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NASA Oceanic Processes Program

Status Report - Fiscal Year 1980

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**NASA Oceanic Processes Program**  
**Status Report - Fiscal Year 1980**



National Aeronautics  
and Space Administration

**Scientific and Technical  
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## PREFACE

Because oceanic remote sensing is coming of age, we view the next decade as an exciting one, with great potential for oceanography. Not only has the remote sensing community demonstrated a spaceborne capability for observing the oceans, but they--together with the oceanographic community--are well along the way in developing a capability to physically interpret the resulting observations. Still ahead of us is the problem of learning how to cope with the huge quantities of satellite data--orders of magnitude greater than those traditionally encountered in oceanography. Even so, a more fundamental problem is the fact that satellite data are essentially two-dimensional and near-surface in nature, and, to have maximum impact on oceanography, we must be able to relate the two-dimensional near-surface information to the three-dimensional structure of the ocean. With this in mind, we are working to effect a closer coupling between the remote sensing and oceanographic communities, so that we will be prepared to optimally exploit the oceanic satellite missions planned for the latter part of this decade.

In this, our first report for the Oceanic Processes Branch, we are particularly interested in identifying the various components of the program, as well as outlining our goals and objectives. Although not a planning document, we believe that it will serve as a benchmark from which our future progress can be assessed. In subsequent years, as the program develops, we will expand the scope of this report so as to include additional information on accomplishments and long-term plans.

We would like to express our appreciation to all those individuals who have contributed material to this report. We are especially indebted to Howard J. Curfman, Jr. and his staff at the Langley Research Center for compiling the material and editing this report.

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## SECTION I---INTRODUCTION

The goals of the Oceanic Processes Program are to provide (1) a physically-unambiguous and scientifically-sound basis for observing the oceans from space, and (2) an effective capability for applying these observations in the solution of oceanic problems. Observational requirements necessary for the solution of such problems are obtained from the oceanographic community, including other Federal agencies, private industry, and academic institutions. The role of the Oceanic Processes Program is to conduct the necessary research and development in order that these requirements may be met. For operationally-oriented spacecraft, this involves the successful demonstration of the performance of a prototype system and subsequent transfer of the program to a user agency. For research spacecraft, this involves a continuation of the program through final data analysis and publication of results. Given this role, the Oceanic Processes Program is focused on, in priority order, the (1) quantitative interpretation of data from spaceborne sensors, (2) rigorous assessment of the value of such data, (3) effective utilization of the resulting vast quantities of data, and (4) development of appropriate improved sensors. The program emphasizes publication of results in the refereed literature.

The research portion of the Oceanic Processes Program is divided into the five following areas, with specific objectives for each:

(1) Marine Boundary Layer, including studies of the near-surface wind field, the use of microwave scatterometers and radiometers to measure these winds, and the development of improved techniques to assimilate these data into numerical oceanic models.

(2) Air-Sea Interaction, including studies of the relations between winds, waves, and currents; the interpretation of data from observing techniques such as synthetic aperture radar and microwave radiometers; and the development of special ship-borne instrumentation necessary for evaluating these measurement techniques.

(3) General Circulation, including studies of the large-scale circulation of the oceans, the use of radar altimeters to observe the surface topography of the

oceans, and means to combine surface topography with geoid and ship-borne observations to infer ocean currents.

(4) Coastal and Inland Waters, including studies of coastal waters and inland seas; the interpretation of color imagery relative to inferring characteristics of phytoplankton, dissolved and suspended materials, and currents; and means to contend with the effect of atmospheric attenuation on color imagery.

(5) Polar Oceans, including studies of sea ice and its response to the influence of the ocean and atmosphere, the interpretation of data from a variety of observing techniques relative to characterizing sea ice properties, and the development of improved techniques for the utilization of these data.

Two closely-related research areas within NASA include Global Weather, which is interested in relating the characteristics of the marine boundary layer to the over-lying atmosphere; and Climate, which is interested in relating long-term ocean and ice variability to climate.

In addition to the research areas noted above, the Oceanic Processes Program is involved--to varying degrees--in the development and evaluation of sensor techniques, as well as the formulation of flight projects and analysis and publication of resulting data (additional information for these may be found in Sections III and IV, respectively). Concerning the latter, the following represents a brief compilation of past, present, and future flight projects and associated studies.

GEOS-3. Geodynamics and Experimental Ocean Satellite; 1975-1978;  $115^{\circ}$  orbit; present activities include data analysis and publication of results.

SEASAT. Experimental oceanographic satellite; 1978;  $108^{\circ}$  orbit; present activities include performance evaluation, data analysis, and publication of results.

NIMBUS-7. Experimental satellite with two oceanographic sensors; 1978-present; sun-synchronous orbit; present activities include performance evaluation, data analysis, and publication of results.

NOSS. National Oceanic Satellite System; to conduct a limited operational demonstration of oceanic remote sensing; planned 1986 launch; sun-synchronous orbit; present activities include initiation of detailed design studies in very near future, and formation of Science Working Group under Francis Bretherton (NCAR) for the purpose of ensuring that the research community is able to optimally exploit the potential offered by NOSS.

TOPEX. Topography Experiment; to determine the general circulation of the ocean via altimetry-derived measurements of the sea surface topography; in order to determine the mean component of the general circulation, an improved geoid--such as is proposed to be obtained by GRAVSAT--will be needed; proposed 1986 launch; high-inclination orbit (105-115°); present activities include initiation of conceptual design study and formation of Science Working Group under Carl Wunsch (MIT) for the purpose of defining science requirements.

GRAVSAT. Gravity Satellite; to determine an improved gravity field for the Earth; proposed 1985 launch; polar orbit; present activities include initiation of conceptual design study and formation of Science Working Group under Dick Rapp (Ohio State) for the purpose of defining science requirements.

ICEX. Ice and Climate Experiment--a proposed research program; present activities include the publication of science requirements by a Science Working Group under Bill Campbell (USGS) and planning for the utilization of the potential offered by NOSS and an as-yet-to-be-defined near-polar-orbiting synthetic-aperture-radar-equipped satellite in meeting these requirements.

Program Managers within the Oceanic Processes Branch include the following:

Vacancy	Marine Boundary Layer
Larry McGoldrick	Air-Sea Interaction
Robert Chase	General Circulation
Martin Swetnick	Coastal & Inland Waters

Frank Carsey	Polar Oceans
Bill Fred Townsend	TOPEX
Ken Carder	Scheduled to arrive in late August to work in Optical Oceanography; on leave from U. of S. Florida

Other closely related Program Managers within NASA  
include:

John Theon	Global Weather
Robert Schiffer	Climate/ICEX
Doug Broome	NOSS
Ray Arnold	Nimbus-7

## SECTION II--FUTURE PROSPECTS

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## CHEMICAL OCEANOGRAPHY

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The future character of chemical oceanographic research is clear (e.g., see National Research Council, *The Continuing Quest*, Nat. Acad. Sci., pp 91, Washington, D.C., 1979). That is, projects of an increased size and multi-disciplinary nature can be expected to increase in number during the next decade. This will undoubtedly involve a need for larger geographical coverage, synopticity and a high rate of data acquisition. Remote sensing from aircraft and spacecraft is ideally suited in this regard. As a result, the desirability for employing remote sensing technology in chemical oceanographic research from both airplanes and satellites is obvious.

Unlike the use that has been made of several sensor systems in physical oceanographic investigations, little, if any application has occurred to date in marine chemical studies. Moreover, with the systems presently available, such application is not entirely obvious at this time. What has been done which in some way can be related to Chemical Oceanography has been accomplished with the Coastal Zone Color Scanner (CZCS), on NIMBUS-7. The parameters being measured are chlorophyll-a and phaeopigments, and thus, are perhaps more appropriate variables for use in marine biological research. Therefore, other than the sensors being used by atmospheric chemists, there is virtually no existing remote sensing capabilities in the field of Chemical Oceanography which can be built upon or be expanded in the next decade. Whatever is to be accomplished depends for the most part upon the results of present and future R&D efforts in sensor technology. Therefore, the impact on marine chemical investigations of any remote sensing systems that may become operational for such studies during the 1980's will be significant. However, it should be realized that these systems are not looked to for replacing research vessels. Remote sensing systems are envisaged as being complementary to ships (e.g., ground truth is essential).

The major categories that can be expected to comprise many active research studies in Chemical Oceanography during the next decade are those involved with bioprocesses from a chemical prospective;

gas and aerosol fluxes; particulate fluxes to and through the marine environment and several global geochemical problems (e.g., the CO<sub>2</sub>, sulfur and nitrogen cycles). Of the passive sensors presently available, infrared and visible systems might have a potential application (e.g., differential spectroscopy). However, a significant amount of research on such employment needs to be done, some of which, because of the nature of the problem, will be exploratory. Nevertheless, it needs to be recognized that the contribution of these sensor systems, as well as those in the microwave region should prove increasingly valuable in marine chemical investigations involving biochemical considerations, such as in a supportive role for delineating fronts and eddys. It is also in regard to these kinds of studies that the CZCS may provide a contribution in the solving of marine chemical problems by allowing chemical parameters to be inferred (e.g., nutrients) from the data provided by this system. Once again exploratory studies could lend credence to this supposition.

The greatest promise of remote sensing in Chemical Oceanography appears to rest at this time with active systems which are being deployed in aircraft. Laser systems presently existing in the experimental stages are generating exciting remotely sensed data. For example, if the broad band fluorescence, having a peak around 590 nm, could be resolved into its various components, lasers could prove to offer an important contribution in the solution of a number of marine organic chemical problems. Coupled with simultaneous measurements of the atmosphere, perhaps one could determine whether or not certain organic compounds found in the atmosphere is the consequence of a flux of matter to or from the ocean, or is simply recycled material. Such information is essential for mass balance calculations. Yet another application of lasers would be in the study of the CO<sub>2</sub> flux between the ocean and the atmosphere, and therefore, possible use in the investigations of various problems involving seawater alkalinity. Finally there are preliminary data which indicate that different clay minerals may generate unique slopes for curves produced when clay mineral concentration is plotted against extinction coefficient. If clay minerals could be differentiated in a mixture by measuring extinction coefficients of a water column, significant application to geochemical and sedimentological problems becomes apparent.

More research still needs to be conducted on the laser systems now in use, as well as the interpretation of the resulting data, before these remote sensing systems can be used operationally. Nevertheless, they do appear to be at the threshold of such employment. For example, real-time measurement of chlorophyll-a profiles is already possible at this time with available equipment. However, even though much, if not most of what has been stated regarding the

potential of remote sensing in Chemical Oceanography can be categorized as conjecture, one fact is irrefutable. That is, unlike the success enjoyed with remote sensing in Physical Oceanography, any similar success that is to be realized in Chemical Oceanography will come about only through diligent efforts being expended on developing systems for this purpose.

## OCEAN CLIMATE

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A major requirement for understanding the role of the oceans in the climate system is the measurement, region by region, of the heat budget of the upper layers and its interannual variability. The components of the heat budget are the net radiation at the ocean surface, fluxes of sensible and latent heat through the surface, lateral transport by ocean currents, and vertical transport from below, to be balanced against changes in heat storage. At present, only the rough magnitudes of some of these components are known for a few areas, and a long-range program of both in situ and remote sensing will be needed to determine them over the globe.

Particularly promising applications of remote sensing from space are:

- 1) The use of AVHRR imagery to provide measurements of incoming solar and, after suitable calibration, an index of net infrared radiation.
- 2) Scatterometer measurements of surface wind stress to determine the vertical velocity, and, coupled with the sea surface temperature, the lateral heat flux associated with the Ekman transport.
- 3) Use of a data collection and location system to track buoys drifting with the near surface current and telemetering in situ measurements of surface and subsurface temperature.
- 4) Microwave measurements to determine the boundary and character of sea ice.
- 5) Altimeter measurements of sea level to determine the regional intensity and statistics of mesoscale eddies.
- 6) The use of patterns of sea surface temperature in infrared imagery, and just possibly of patterns of color in the visible, to locate ocean fronts, and in particular to monitor the statistical variability of the boundaries of certain current systems.

If some potential improvements in accuracy can be achieved in practice:

- 7) The global mapping from infrared of persistent regional scale sea surface temperature anomalies would be an important element in monitoring the heat budgets (particularly in combination with an atmospheric general circulation model to estimate surface fluxes).
- 8) Given adequate satellite tracking, changes with time of sea level on the scale of an ocean basin would provide unique information on seasonal and interannual variability in the ocean circulation (e.g., the equatorial undercurrent, the Gulf Stream).
- 9) Given also good independent measurements of the geoid, determination of the time averaged surface geostrophic circulation on a global basis would have a very far reaching impact.

More speculative, but potentially of major importance are:

- 10) The statistical interpretation of microwave and infrared derived measures of cloudiness and rain water concentrations to yield the cumulative precipitation over the oceans, and hence, coupled with fields of wind and precipitable water, to estimate the average evaporation rate (latent heat flux).
- 11) To use AVHRR imagery to provide an index of combined sensible and latent surface heat flux from low-level cloud structure, coupled with remotely sensed wind and stability in the lower troposphere.
- 12) Inexpensive packages on expendable floats which drift at predetermined depths for several months before rising to the surface for identification and location from satellites would permit a new approach to the whole ocean circulation and in particular to the ocean heat transports.

My personal research will be on integrating such information into models of the combined ocean atmosphere climate system, and in the development of methodology for items 6, 7 and 11.

## UPPER OCEAN VARIABILITY

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Temporal and spatial variations in the structure of the oceans upper layers occur on various scales from the large scales of the seasonal and climatic variations of the general circulation to the small scales characterizing turbulence, internal waves and surface waves.

In recent years dramatic progress has been made toward relating temporal variation of the upper ocean over large spatial areas to atmospheric forcing on time scales of hours to days. On this scale the ocean/atmosphere connection is relatively local and the ocean responds primarily to local wind stress and heat exchange by radiation, evaporation and sensible heat transfer. Variations on this scale can be reasonably well predicted when the atmospheric forcing is adequately known. Operational predictions over most of the ocean are not, however, possible because the requisite forcing fields (particularly wind stress, net radiation, and atmospheric humidity) are not available. As remote observations of sea surface temperature, wind stress and net radiation through the sea surface are perfected, there will be an improving ability to carry out and verify such predictions on a world-wide basis. One may anticipate an active dialogue between ocean modelers and those providing the data in an attempt to achieve a more accurate assessment and prediction of ocean/atmosphere exchange. But because the ocean/atmosphere exchange on longer time scales will not soon be predictable from any feasible operational observing system, the need for in situ observations to characterize the ocean structure on the large scale will continue, and even accelerate. Ship-of-opportunity and free-drifting buoy observations of ocean temperature and velocity, as well as atmospheric parameters, will continue to be economic methods to achieve the necessary information over broad regions.

As the horizontal and temporal resolution of oceanographic observations has increased over the last few decades a plethora of meso-scale ocean phenomena has been discovered and examined. Considerable attention has been devoted to mesoscale eddies ranging from the highly energetic warm and cold core "rings" observed near powerful western boundary currents to their less energetic but apparently ubiquitous mid-ocean relatives. Particularly near eastern boundaries along which upwelling is frequent, a class of mesoscale variability ranging from coastal fronts through upwelling plumes and topographically related eddies have been observed. And in the deep ocean,

far from apparent topographic influences, remarkably sharp spatial variations are observed to be associated with the surface general circulation and mesoscale eddies. These various mesoscale phenomena are all of intrinsic interest but, beyond that, they are important in the aggregate as the mechanisms by which properties such as heat or biological nutrients are transported, that is they are the "eddies" which are crudely accounted for in ocean models as eddy diffusion.

Much of what is known about the spatial structure of upper ocean mesoscale variability has been learned from remote, spatially extensive observations of sea surface temperature and color. The uncertain calibration of these observations is less a problem on these scales, and as resolution has increased, more details of the ocean processes have been exposed. The interpretation of patterns of such naturally occurring tracers is presently primarily descriptive since we do not yet know how to "invert" this information to measure quantities of dynamical interest, such as velocity and heat content. In the near future one may expect an oceanographic emphasis on research programs aimed at specific mesoscale phenomena in which in situ and remote observations are coordinated. Direct measurements will continue to be used to examine the phenomena and at the same time provide a reference for relating remotely observed signatures to dynamically important processes, at least at selected sites. Unlike "sea-truth" experiments, the objective of these experiments is not to verify remote observations but rather to learn how their unique features can be exploited for more than descriptive purposes.

A concrete example of the needed interplay between remote and in situ observations is provided by coastal circulation studies along the west coast of the United States. Particularly during the summer, equatorward winds are favorable to upwelling which causes the surface layer over the continental shelf to be carried offshore and be replaced by cold, nutrient rich water from below. Satellite sea surface temperature observations, when not blocked by cloud cover, give a clear picture of the rapidity and structure of upwelling events. At the same time they show a complex field of eddies, swirls and fronts, some of which appear related to topography while others clearly propagate. Particularly for examination of this eddy field, the spatial coverage provided by remote observation is attractive but in order to exploit this it is necessary to first answer from direct observation questions like: How well do surface temperature patterns serve as tracers from which velocity may be determined? How deep are the patterns of different size and shape? What is the associated heat transport? Are the patterns observed during clear periods found at all times or are they linked to the same meteorology which makes seeing possible?

In summary, the next few years promise a series of studies in which remote and direct observations are combined both to better describe the processes producing upper ocean variability and to determine how to exploit the unique features of remote observations to monitor them.

## WIND-DRIVEN OCEAN CIRCULATION

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The movement of the ocean is driven by the input of heat from the sun, input of momentum by the atmospheric surface wind stresses and the tidal forces of the moon and sun. Mariners have known of these causes of upper ocean circulation since the first voyages. Since the 1950's, we have known that the very large (but steady) gyre scale circulation at middle latitudes is directly driven by the curl of the wind stress over the subtropical oceans. In recent years, oceanographers have become more aware of smaller features such as mesoscale eddies, Gulf Stream rings and meanders, ocean fronts, etc. It is not known to what extent these intermediate scale features are driven or, at least, excited by wind variability. This lack of understanding is primarily due to a lack of data on the winds over the ocean on the appropriate time and space scales.

At low latitudes there are interesting major current systems. In the Pacific there exists westward flowing South and North Equatorial currents and westward flowing equatorial countercurrent. Recent work by Busalacchi and O'Brien (1980) indicates that the seasonal migration and amplitude variability of these low latitude current systems can be reproduced in numerical models of the ocean if we know the windfield. They use almost 5 million ship winds to produce mean monthly wind stress distributions to drive an ocean model.

In the Indian Ocean, the monsoon circulation directly drives the reversal of the ocean surface currents in the western Arabian Sea. Expeditions during the World Weather Watch have documented the effect of wind variability on upper ocean variability in the region both along the Somali Coast and on the equator.

In the Atlantic Ocean at low latitudes we have evidence from GATE and French data that the distribution of wind must be known to explain the variability of the upper ocean currents. For example, the summer-time upwelling in the Gulf of Guinea has been explained by the onset of the southeast trades in the western Atlantic.

The first numerical ocean modelling paper on an ocean scale was published by Bryan in 1963. Since then the oceanographers have developed the capability of building reasonable models of wind driven ocean circulation. Unfortunately, they haven't had sufficient wind data to force realistic models.

Satellites may be the tool to get spatial and temporal coverage of the windfield over the ocean. If the proposed methods of measuring windspeed and direction from NOSS really work, ocean modellers will have wind stress distributions over an entire ocean basin and can perform some exciting calculations. If sea level can be monitored accurately enough to estimate geostrophic currents using TOPEX, we will have data to verify the wind driven ocean circulation models.

Naturally we will learn a tremendous amount about upper ocean variability using good numerical models of wind driven circulation. However, the society payoff can be enormous. The knowledge of upper ocean circulation and its variability can impact on fisheries, ship routing, iceberg drift, search and rescue, oil spill trajectories, weather prediction, understanding short range climate, etc. If our numerical models can explain a large percentage of the natural variability, we can then study the influence of the thermally driven part of the ocean circulation.

Realistic ocean circulation models require large computers both for the simulation and verification stages. It will be necessary to use horizontal grid elements of no larger than 20 km to calculate accurately the wind driven circulation. Even in a modest size ocean basin such as the North Atlantic, this restriction represents an economic handicap. If models have larger horizontal grid elements, then turbulence parameterizations become critical in controlling the model physics. Since we do not have any understanding of turbulence in the ocean on the 10-50 km scale, the models using large grid sizes are not well received by the scientific community.

## MARINE BOUNDARY LAYER AND AIR-SEA INTERACTION

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Investigations of the marine atmospheric boundary layer and air-sea interaction may be significantly aided by remote sensing measurements from satellites during the coming decade. The ability of satellites to make repeated measurements over entire ocean basins is of particular importance for the study of spatial and temporal variability of boundary layer structure and air-sea transfers of momentum, heat and mass.

As a way of illustrating the potential impact of satellite measurements on our knowledge of the marine and oceanic boundary layers, we describe below a hypothetical experimental program which might be conducted during the 1980s.

Objectives. The objectives of the program follow to a large extent from the demonstration, based on SEASAT scatterometer data, that satellite-derived surface winds are accurate to within 1 to 3 m/s in speed and  $\pm$  10 to 20 deg in direction. Specific objectives follow:

- Investigate the spatial and temporal scales of variability of the surface wind and stress field over the ocean including its relation to the surface pressure field (geostrophic wind), static stability, depth of the boundary layer and roughness of the sea surface.
- Investigate the response of near-surface ocean currents to wind forcing on the small scale (wind stress) and the large scale (curl of the wind stress).
- Investigate the feasibility of inferring air-sea transfers of heat, water vapor, and rain from satellite measurements supplemented by a few direct measurements.
- Investigate the feasibility of determining the surface pressure field from the surface wind field for use as initial conditions in numerical weather prediction.

Observations. Observations would be required, not only from satellites, but also from in situ platforms to complement the satellite observations and to provide ground truth for improving algorithms and sensors. The listing below is not exhaustive.

- Satellite observations
  - surface wind, stress
  - surface temperature
  - air temperature, humidity
  - clouds (wind velocity, radiation)
  - rainfall
- Drifting, drogued buoys (data telemetry via satellite)
  - surface currents (satellite-tracked buoys)
  - water temperature
  - air pressure
  - air temperature
  - humidity (development required)
  - surface wind
- Special platforms for local investigations and ground truth
  - moorings - currents and temperature vs depth
  - meteorological variables
  - aircraft - boundary layer structure
  - experimental remote sensors
  - research vessels - detailed local surveys
  - experimental in situ sensors

Results. The results of the hypothetical experiment would have potentially far-reaching effects in several areas of research and practical applications. Guidance would be provided to efforts to model the interaction of the upper ocean and lower atmosphere. The global measurement of air-sea transfers of heat and water vapor are fundamental to our understanding of the effect of the oceans on climate. The use of surface pressures (obtained from satellite-derived surface winds and directly from the drifting buoys) as initial conditions for numerical prediction might significantly improve the quality of weather forecasts, particularly off the west coast of the U.S.

It should be emphasized that an experiment along the lines described above requires an integrated program of measurements from both satellites and other platforms. The merged and blended in situ and remotely sensed measurements would enhance each other and at the same time provide improved interpretation of remotely sensed signals and the development of improved instruments.

## BIOLOGICAL OCEANOGRAPHY

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One of the central issues in modern marine ecology relates to the importance of spatial heterogeneity for the dynamics and stability of the ecosystem. This is the celebrated problem of "patchiness". In the phytoplankton (Platt, 1972; Denman and Platt, 1975), patchiness has been studied through time (or space) series of *in situ* fluorescence (an index of chlorophyll concentration). The derived power spectra of chlorophyll fluctuations have been interpreted according to the available theories on the origin of patchiness (Denman and Platt, 1976; Denman *et al.*, 1977). Both of these theoretical treatments predict a change in slope of the (logarithmic) power spectrum of chlorophyll at a characteristic wavenumber whose magnitude depends on the relative magnitudes of phytoplankton growth rate and the energy dissipation rate of the turbulent field. At higher wavenumbers, the spectrum is thought to be controlled by physical processes; at lower wavenumbers control is thought to be primarily biological. Attempts to observe this spectral break from shipborne measurements have been frustrated by the fact that the expected value of the characteristic wavenumber ( $1/k \sim 10$  km) is too close to the lowest wavenumber resolvable by the spectral analysis.

The only way out is to look at data with a larger synoptic scale, such as can be achieved from remote sensing. Chlorophyll can be sensed by multispectral scanning sufficiently well to look at the larger scales of the chlorophyll spectrum out to scales of 100's of km and to see whether this shape changes with time in a given area of the ocean. This would be a fundamental and significant contribution to biological oceanography.

Another potential application relates to using ocean colour measurements to identify areas of high phytoplankton biomass in connection with studies of the effects of physical fronts on biological productivity. This subject is certainly a topical one in biological as well as physical oceanography (Bowman and Esais, 1978). Repeated passes with ocean color and temperature

sensors offer the possibility to study the stability of fronts and the evolution of the biological fields during frontogenesis and frontolysis. This would be particularly useful in areas difficult of access by ship, such as the high Arctic.

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## GEOLOGICAL OCEANOGRAPHY

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Application of remote sensing techniques from satellites and aircraft to marine geological problems are restricted primarily to relatively shallow waters and to processes that occur within the near-surface layer of the ocean. Both limitations indicate that such techniques can contribute more effectively to studies in the coastal ocean, including continental shelf waters, than in the open ocean. Remote sensing probably could contribute in a fundamental way to the solutions to two important geological oceanography problems described briefly below.

1. Fine-Grained Sediment Systems. Because particulate matter strongly affects the quality of the marine environment in a variety of ways, the ability to predict its behavior is of the greatest scientific and practical importance. This is particularly true of the fine-grained fraction which poses the greatest problems: economic, aesthetic, and environmental. The goal is to understand how fine-grained sediment systems operate. The important questions include: (1) What are the sources of sediment, their locations and strengths? (2) What is the character of the material introduced, its size distribution and composition? (3) What are the routes and rates of transport? (4) What are the sites and rates of accumulation?

Our knowledge of fine-grained sediment systems in the coastal ocean is poor. Coastal systems are heterogeneous in many of their characteristic properties and sediment sources vary markedly temporally. Adequate characterization with conventional shipboard techniques requires many samples collected nearly synoptically, and observations over long periods of time--an impractical task. Remote sensing from the air probably could contribute substantially to our understanding of coastal sediment systems, but it will require analysis and interpretation far more sophisticated than has been done in the past. To improve this situation a critical assessment should be made of the capability of existing and proposed air-borne sensors: (1) to distinguish organic from inorganic particles, (2) to mea-

sure the concentration of total suspended solids and over what range, (3) to integrate over the water column to estimate the total suspended load, and (4) to estimate the partitioning, by sedimentation, of suspended matter among the different segments of a coastal system. Once the capabilities of sensors to deal with these questions have been established, they should be compared critically with the characteristics of natural systems. Only in this way can we assess the ability of remote sensing to resolve these problems and establish what sea-truth measurements are required for calibration of remote sensing observations.

2. Events and Coastal Sediment Systems. Events such as floods and hurricanes can dominate the sedimentation and natural evolution of coastal systems in spite of their infrequent nature. Synoptic observations are desirable during and immediately following events because properties change rapidly in time and space. Shipboard observations during this period are difficult to make and synoptic observations over relatively large areas are virtually impossible. While clouds may rule out satellite observations during episodic weather events, low flying aircraft may be useful.

Episodic weather events usually can not be predicted very far in advance. The key to effective scientific studies is rapid response. Aircraft that could be deployed quickly with appropriate remote sensing packages could provide valuable data for science and management.

The important geological questions include: (1) During floods how much sediment is discharged to the coastal ocean? (2) What are the principal sources of this material? (3) Where is the material deposited? (4) How rapidly do levels of suspended sediment recover to natural levels? (5) What changes in the shoreline are produced by episodic storms? (6) How rapidly do shorelines recover? (7) What is the importance of events, relative to average conditions, in determining the geological evolution of coastal systems?

Remote sensing could contribute significantly to the resolution of a number of these questions. Sea-truth data will be required also, not only for calibration of remote sensing data, but to extend the observations to greater depth.

## SURFACE WAVES

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Ocean surface waves range from large storm waves with lengths of hundreds of meters and heights of tens of meters of importance to commerce and coastal installations to wavelets of centimeter size of importance to remote sensing of surface wind speeds and the interchange of energy, momentum, and mass between the oceans and the atmosphere. These extremely large and small waves are very difficult to measure using conventional methods, but new techniques developed for sensing the sea surface remotely work well in these applications and now provide the best measurements of surface waves.

Radar altimeters accurately measure from space the standard deviation of the roughness of the sea surface, a quantity that is one quarter the significant wave height. Such radars have flown on GEOS-III and on SEASAT and will provide routine global observations of wave height when flown on such operational satellites as NOSS. These observations will lead to atlases of wave climate, and when coupled with satellite measurements of oceanic wind and existing wave forecasting models, will lead to accurate descriptions of oceanic wave fields and forecasts of these fields twelve to twenty-four hours into the future.

Synthetic-aperture radars which map the distribution of radio scatter from the surface see the larger, longer waves and provide estimates of dominant wavelengths and directions. Over the open ocean this information supplements that from radar altimeters, but more importantly, the radar images show wave propagations, focusing, and shadowing in coastal areas, and the interaction of waves and currents. These observations will lead to a better understanding of wave climate along shores and in the core of strong currents where large dangerous waves can be formed under favorable conditions.

Lastly, all radars which view the sea at incidence angles well away from vertical provide estimates of the amplitude, direction, and frequency of those centimeter wavelets that are resonant with the radar wavelength, estimates that were nearly impossible with earlier techniques. This allows radars to study the response of wavelets to wind, currents, and other waves, studies of fundamental importance to air-sea interaction and to remote sensing of the sea surface.

Future work is directed toward extending the usefulness of the radio techniques. For example, can altimeter data be used to measure wavelengths, SAR data to measure wave heights, and radar scatter to estimate wind stress?

## SEA ICE

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Sea ice is a field where remote sensing can have a great impact on a wide variety of different types of problems in the 1980s. Sea ice areas are shrouded in darkness during the winter and by clouds during the summer. Conventional field operations are invariably expensive and difficult and frequently hazardous. The area affected by ice is quite large, approximately 11% of the World Ocean, and the characteristics of the ice may change in important ways, such as the opening and closing of extensive lead systems, in the time span of a few hours. During certain times of the year the position of the ice edge may exhibit advective velocities of the order of 25 cm/sec over a period of months. The large-scale characterization of this very dynamic system can only be obtained via the utilization of all-weather remote sensing systems that are capable of imaging large areas of the polar regions at reasonably high resolutions with repeat times of a few days or less. These rather stringent requirements are tempered by two factors: the signature of sea ice is both strong and commonly strikingly different from the signature of the surrounding water and land areas. Also, because observations of sea ice are so limited, even rather crude measurements of ice characteristics and extent can be of considerable scientific importance.

Current and potential capabilities of different types of satellite-borne remote sensing systems as applied to sea ice are as follows:

Passive microwave: Passive microwave systems have proved invaluable in the global monitoring of ice extent because of the large difference in brightness temperature between ice and water. Increases in resolution and the rapid production of more useable map-correct imagery appear to be attainable and will further enhance the usefulness of these systems. There are, however, continuing problems with developing more detailed interpretations of such imagery in that the observed brightness temperature is (at a given frequency) a function of at least four variables (open water fraction, ice thickness, ice age, snow cover, and temperature). The answer is, of course, multifrequency observations coupled with careful ground-truth measurements leading to suitable discriminatory algorithms. As the pixel size at different microwave frequencies is invariably different this will not be a simple task.

Active microwave: Synthetic aperture radar has great potential in sea ice studies in that it provides a map on which the strength of the return is largely determined by the nature of near-surface ice and the physical roughness of the surface topography. One can differentiate 1st year from multiyear ice as well as observe the patterns of deformed ice. By tracking the many identifiable targets on sequential images, the velocity field of the ice pack can be

specified. This, in turn, can be used to calculate a strain field and a strain history and to estimate an ice thickness distribution. It is also possible to trace the general ice edge and delineate lead systems. In addition icebergs, floebergs, and ice islands, all major hazards to offshore operations, can be identified and tracked. Work is needed to develop ways to speed the analysis of SAR data so that the map-correct coordinates of any point can be rapidly determined and strains and strain rates calculated. Existing ice dynamics models must also be modified to accept such new information. Another active system with considerable potential in the study of sea ice is radar and laser altimetry which has the capability of determining the distribution of the heights of the roughness elements on the sea ice surface. To verify these techniques further theoretical and field verification studies will be required.

Visible and IR: Such imagery will continue to be of considerable use. As contrasted to the all weather capability of microwave systems, IR and visible systems are limited by clouds and by clouds and darkness respectively. These are serious limitations as much of the dynamic activity of pack ice appears to occur under the "cover" of atmospheric lows. IR reveals the "hot" areas associated with open water and thin ice that are important in studies of the thermodynamics of the pack. Unfortunately, the presence of a little snow greatly complicates the interpretation of such imagery. Visual imagery, particularly imagery that has a map-correct format, such as that produced by LANDSAT, will continue to be useful, primarily as a source of occasional "control" in the development of methodology for handling the output of weather-independent sensors.

In short, satellite-borne remote sensing can, with proven systems, produce a major advance in our knowledge of the world's sea ice cover. In the 1980s there should be additional improvements in these capabilities particularly relating to techniques for rapidly processing and analyzing the data and transmitting the results to a wide variety of users. What is currently lacking is an adequate platform for deploying combinations of sensors in a suitable polar orbit. Once this occurs the ability to routinely utilize simultaneously collected multi-sensor data in sea ice studies will be greatly enhanced.

To temper the impression that the deployment of such multisensor systems would be a cure-all, it should be noted that ice blocks satellite observations of the ocean thus limiting the collection of data that are important to studies of the ice itself. Therefore the development of improved buoys that are capable of ice deployment and of characterizing the upper ocean and the lower atmosphere are also an essential part of any operational ice remote sensing program.

## GENERAL CIRCULATION OF THE OCEANS

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The major obstacle to understanding the ocean circulation is in the difficulty of observing it properly. Our picture of the general circulation of the ocean and its variability is largely dependent upon two distinct types of observations. The first is the record of the distribution of water density in the ocean, built up over the past 50 years from ships. Treating the data as though it were taken almost simultaneously, we have a picture of the gross structure of the ocean circulation, although aliased to an unknown degree. The other form of measurement has been the recent use of intensive spatial deployments of moored and drifting instrumentation for periods of order a year. These "cluster-type" experiments have shown a very energetic variability in the ocean circulation with periods of order 25 days and longer.

To fully measure and understand the circulation of the ocean and its variability, we need to fill the gap between the large scale ocean-basin wide surveys by ships which take years, and the cluster-type experiments which can give instantaneous pictures of the circulation, but only over extremely limited areas, and even then, only in regions of comparatively low currents. Because there are many analogs between the ocean circulation and the circulation of the atmosphere, we can now clearly see that, to carry our understanding of the ocean at least to the levels of understanding of the atmosphere, we need the equivalent of the meteorologists global observation network and their regional networks.

The great promise of remote sensing techniques is that for the first time, they permit us to contemplate observing the ocean as a whole. Current technical developments allow one to foresee the possibility of the following kind of observational system.

Satellite altimeters will allow construction of global maps of the surface geostrophic velocity and its variations on space scales from 25 km to entire ocean-basin widths, and on time scales from days to years. Scatterometers can define the vector wind field which represents the major direct driving of the ocean circulation. By itself, these two measurements would provide oceanographers with the equivalent of the meteorological surface pressure and surface forcing fields. Since knowledge of ocean dynamics has advanced to the point that surface variability can be used with a reasonable degree of confidence to calculate the interior variability, at least two measurement techniques then would be available for exploration of the interior ocean velocity and density fields. More generally, numerical modeling efforts are continuing which, in a few years, ought to give highly realistic ocean circulation if constrained by these remote sensing measurements. Another remote sensing technique (but not a spaceborne one) is acoustic tomography. If the proposed system works as envisioned, it would be capable of resolving the full three-dimensional density field of the ocean over entire basins every few days. Using altimetrically determined surface velocities, the two systems together would be capable of direct measurement of the entire geostrophic flow field from top to bottom every few days, in real-time if required. Here, finally, would be the oceanographic equivalent of the complete meteorological observation network.

Given such a system, a number of benefits would occur. For example, operational routing of ships in regions of strong currents would be possible. One would also have, for the first time, an actual measurement of the "climactic state" of the ocean and be able to see if it changes in any significant way. Many kinematical questions, e.g. the relationship between the rapidly moving Gulf Stream and its surrounding eddy field would be answered, leading eventually to dynamical understanding and an actual forecast skill. In a general way, coupled with surface wind measurements, understanding of the ocean would become accessible in a quantitative way.



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## THE GEODYNAMICS AND EXPERIMENTAL OCEAN SATELLITE PROJECT (GEOS-3)

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### THE GEOS-3 MISSION

The GEOS-3 mission was designed to improve man's knowledge of the earth's gravitational field, the size and shape of the terrestrial geoid, deep ocean tides, sea state, current structure, crustal structure, solid earth dynamics, and remote-sensing technology. Instrumentation included: a dual-mode radar altimeter, C-band and S-band transponders, doppler beacon, and laser reflectors. The GEOS-3 altimeter was designed to provide the means for establishing the feasibility and to demonstrate the capability for directly measuring or inferring geodetic oceanographic and geophysical parameters through the reduction and analysis of the altimeter height measurements and the form and structure of the return wave form (pulse) shape. The GEOS-3 satellite was launched on April 9, 1975 from the Air Force Western Test Range. The achieved orbit parameters are mean altitude 843 km, inclination 114.98°, and eccentricity 0.001. Mission data collection began on April 21, 1975 and continued through December 8, 1978. Program/project responsibilities include: NASA Headquarters Geodynamics Branch - Program Management, NASA Wallops Flight Center - Project Management, NASA Goddard Space Flight Center - Mission/Operations.

### GEOS-3 INVESTIGATIONS

Proposals from the scientific community were solicited by NASA for investigations in 13 different categories which include: (1) ocean geoid, (2) ocean tides, (3) sea state, (4) currents and circulation, and (5) gravity model improvements. In each of the areas of investigation, with the possible exception of ocean tides, the GEOS-3 data have been successfully utilized both to further scientific knowledge and to provide real and practical applications of remotely sensed data. All of the project objectives have been satisfied, and in most cases the data proved to be useful beyond expectation. Several of the investigation areas are discussed below.

Ocean Geoid: The ocean geoid as determined by GEOS-3 altimetry, when compared to the best existing geoids determined by satellite and gravimetric methods, shows significantly enhanced detail at the short and medium wavelengths. It also provided the first comprehensive data set in most areas of the world's oceans. Further

refinements of data-handling techniques and expansion of the presently analyzed data set are certainly indicated.

Sea State: Analysis of GEOS-3 return wave form data to determine significant wave heights has produced results which have been accepted by both the scientific and the industrial community as being comparable to buoy-collected data. A variety of data-handling techniques have emerged, and all have been successfully tested. However, at this time no sea state prediction model capability is known to exist that is capable of utilizing the altimeter estimates.

Currents and Circulation: Analysis of GEOS-3 height data has resulted in the determination and location of temporary departures from the geoid, such as currents, eddies, storm surges, etc. A prime example is the studies of the Gulf Stream, where the boundaries, dynamic heights, and velocity estimates have been routinely produced. Results in this area have gained acceptance by the user community and show great promise for future altimeter missions.

Wind Speed: Although not anticipated prior to launch, analysis of the GEOS-3 altimeter wave forms revealed that it was possible to estimate surface winds speeds (non-directional) over the ocean areas. These results also favorably compare with buoy data, but like the wave height data, no operational use has emerged.

Terrain and Ice: Again, it was not anticipated that the GEOS-3 altimeter would maintain track over terrain or ice; however, results to date have indicated numerous areas for potential future altimeter activity. Sufficient information has been gained to allow further optimization of the instrument.

Further results can be found in JGR, Volume 84, dated July 30, 1979.

#### GEOS-3 DATA STATUS AND AVAILABILITY

The GEOS-3 altimeter data set consists of 1410 hours of data in 9000 segments. Recently the entire data set was reprocessed using refined techniques and precision laser orbits. This refined data set is archived at the NOAA/Environmental Data and Information Service, Satellite Data Services Division, Washington, DC 20233

## SEASAT DATA UTILIZATION PROJECT (SDUP)

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The Seasat satellite was launched from the Western Test Range, Vandenberg, CA on June 26, 1978. After 106 days in orbit a short circuit in the electrical power subsystem resulted in the loss of the satellite. During the three months of orbital operations, the satellite returned a very large volume of data from the worlds oceans. Many of these data had never before been available. Dozens of tropical storms, hurricanes and typhoons were observed, and two planned major intensive surface truth experiments conducted. A careful assessment of mission objective achievability suggested that the primary proof-of-concept objectives of Seasat would be achievable with the data set, both satellite and surface truth, in hand. The Seasat Data Utilization Project was formed with the general object of determining the utility of the Seasat-A microwave sensors as oceanographic tools, as expressed by the goals of the original Seasat-A Project.

The Seasat-A satellite was designed to carry five sensors including a radar altimeter (ALT), a Scatterometer (SASS), a Scanning Multichannel Microwave Radiometer (SMMR), a Synthetic Aperture Radar (SAR), and a Visible and Infrared Radiometer (VIRR). Precision of the altimeter height measurement was expected to be 10 cm RMS for sea states less than 20 m. The estimate of significant wave height was expected to be accurate to  $\pm 0.5$  m or 10%, whichever was greater. As a goal, the SASS surface winds were to be determined to  $\pm 2$  m/s or 10% in magnitude, whichever was greater, and  $\pm 20$  deg in direction. Two primary classes of data obtained from SMMR were sea surface temperature (SST) and surface winds. The SST accuracy was expected to be  $\pm 2$ K, an important first step in determining SST under cloudy conditions. The accuracy of surface wind measurements was expected to be  $\pm 2$  m/s or 10%, whichever is greater. The SAR goal was to measure oceanic wavelengths and direction of 50 m or greater, sea ice features, iceberg detection, wave-land interfaces and penetration to the surface through major storms such as hurricanes. The VIRR was intended primarily for feature identification.

The Seasat data will be available through the NOAA Environmental Data and Information Service (EDIS). Interim global data records of selected areas are currently available and are described in the EDIS Satellite Data Users Bulletin. Results of the geophysical evaluation are primarily contained in the Seasat Gulf of Alaska Experiment Workshops I and II, JPL Reports 622-101 and 622-107. NASA Headquarters, Environmental Observation Division sponsored the Seasat program with JPL responsible for project management.

SEASAT RADAR ALTIMETER/PRECISION ORBIT  
DETERMINATION EXPERIMENT TEAM

TEAM LEADER: Dr. Byron D. Tapley, Dept. of Aerospace Engineering  
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OBJECTIVES:

The objectives of the SEASAT-I Radar Altimeter/Orbit Determination Experiment Team are: (1) to assess the accuracy of the sensor measurements of  $h$ , the altitude of the spacecraft above the sea surface,  $H_{1/3}$ , the sea-state as measured by the average height of the highest 1/3 of the waves and  $\sigma_o$ , the sea surface back scatter coefficient or the ratio of the reflected to the incident power; (2) to determine the ability of the SEASAT-I data set to perform the task of global monitoring of wave height, global mapping of the ocean geoid, precise measurement of the sea surface topography to detect currents, tides and storm surges, to locate and map the ocean current patterns; and (3) to assess the accuracy with which the SEASAT-I satellite ephemeris can be determined and to define and develop the associated methodology to improve the ephemeris.

RESULTS:

The experiment team has completed a preliminary assessment of the accuracy of the altimeter measurements and the algorithms used to reduce the measurements to geophysical data. The conclusions reached include the following: (1) The noise in the altimeter measurement is less than  $\pm 10$  cm (actually 5 to 8 cm) for significant wave height measurements  $H_{1/3} \leq 8$  M. (2) The ability to monitor ocean topography on the submeter level has been demonstrated by investigating altimeter passes over the Gulf Stream. (3)  $H_{1/3}$  measurements, accurate to 0.5 m or  $\pm 10\%$  whichever is greater, have been validated for wave heights up to  $H_{1/3} \leq 8$  m. (4) The  $\sigma_o$  measurements from the altimeter agree with the scatterometer radar cells within specifications for ranges of  $2 \leq \sigma_o \leq 16$  db (wind speeds from 2 to 30 m/sec). (5) The present accuracy with which the radial component of the SEASAT-I orbit can be determined is 1.5 m. (6) The bias in the altimeter time tag has been estimated to be  $-79.38 \times 10^{-3}$  sec while the overall bias in the height measurement is estimated to be  $.11 \pm 0.15$  m.

Further details on the results of the experiment team activities are given in Ref. (1) through (4). These reports were based on the activities conducted at the four different SEASAT sponsored workshops.

ALTIMETER/PRECISION ORBIT DETERMINATION EXPERIMENT TEAM:

The members of the SEASAT-Radar Altimeter/Precision Orbit Determination Experiment Team are:

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R.L. Bernstein, Scripts Institute of Oceanography, Ocean Surface Topography

George H. Born, Jet Propulsion Laboratory, Orbit Determination, Altimeter Corrections Algorithms

H. Michael Byrne, NOAA PMEL, Ocean Surface Topography

John M. Diamante, NOAA National Ocean Survey, Ocean Tides: Measurements and Models

Bruce C. Douglas, NOAA National Ocean Survey, Ocean Tide, Models and Orbit Determination

Leonard Fedor, NOAA Environmental Research Lab, Co-ordinator for Significant Wave Height Algorithm and Wind Speed Evaluation

E.M. Gaposchkin, Smithsonian Astrophysical Observatory, Orbit Determination

Michael Lefebvre, C.N.E.S./G.R.G.S., SURGE Representative

James Marsh, NASA Goddard Space Flight Center, Geoid, Ocean Surface Topography, Orbit Determination

Mike Parke, Jet Propulsion Laboratory, Geophysical Correction Algorithms and Tide Model

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William F. Townsend, NASA Wallops Flight Center, Sensor Representative and Instrument Correct Algorithms

John Whitehead, Woods Hole Ocean Institute, Ocean Surface Truth

Peter Wilson, Institut for Angewandte Geodasie, SURGE Representative

Jay Zwally, NASA Goddard Space Flight Center, Solid Surface Topography Measurements: Ice Application

Jack Lorell, Jet Propulsion Laboratory, Sensor and Geophysical Correction Algorithms

Clyde Goad, NOAA NGS, Tide Models, Orbit Determination and Geophysic Correction Algorithm

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## SEASAT SCATTEROMETER EXPERIMENT TEAM

Chairman Willard J. Pierson, CUNY Institute of Marine and Atmospheric Sciences The City College, Convent Ave. at 138th St., N.Y., N.Y. 10031 (516) 690-8315.

To develop theories, model functions and algorithms for computing vector winds from backscatter measurements made by the SASS, as calibrated by aircraft underflights and as corrected for attenuation with SMMR data, and compare these winds with conventionally measured winds and theoretically derived wind fields.

- V. Birrer, Univ. of Kansas, Attenuation and Model Function.
- D. H. Boggs, JPL, Computer Program Development and Graphics.
- E. M. Bracalente, La RC, Sigma Naught Programs and Primary Calibration of SASS.
- R. A. Brown, Univ. of Wash., Planetary Boundary Layer Models.
- V. E. Delnore, LTV, Aircraft underflight cross calibration.
- G. G. Dome, Univ. of Kansas, Attenuation and Model Function.
- J. A. Ernst, NESS, Comparisons with conventional data.
- I. M. Halberstam, JPL, Comparison with conventional data, model function comparisons.
- W. L. Jones, La RC, Panel Chairman all activities.
- J. L. Mitchell, La RC, Statistical Programs and Comparisons.
- R. K. Moore, Univ. of Kansas, Theory of Model Function, Model Function Development, attenuation.
- J. E. Overland, PMEL, Practical Applications, Boundary Layer Models.
- S. Peteherych, AES, Anemometer Data Processing, Wind Comparisons.
- W. J. Pierson, CUNY, Model Function Development, Properties of mesoscale turbulence, "Error" analysis, anemometer data processing.
- L. C. Schroeder, La RC, Statistical data analysis.
- J. L. Sweet, La RC, Computer programming, data analysis.
- F. J. Wentz, Remote Sensing Systems, Model function development, attenuation, data processing.
- P. M. Woiceshyn, JPL, Boundary layer analysis, data analysis.
- M. C. Wurtele, UCLA, Boundary layer models, wind field comparisons.

SEASAT SCANNING MULTICHANNEL MICROWAVE  
RADIOMETER EXPERIMENT TEAM

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The experiment team's objective is to evaluate the capability for global, all weather determination of the geophysical variables of sea surface temperature, sea surface wind speed, integrated atmospheric water vapor and liquid water, and rainfall rate from SEASAT Multichannel Microwave Radiometer (SMMR) measurements.

The approach has been to gather surface truth data, produce colocated determinations from spacecraft measurements, and hold workshops of one week's duration for intensive comparison and evaluation.

The team progress has been to show:

1. Sea surface temperature determinations are internally consistent to about 1.5K with biases of several degrees. Some coupling of retrievals to estimates of wind, water vapor is present for winds greater than 10 m/s or for clouds in field of view.
2. Sea surface wind speeds for a significant subset of data are accurate to about 2 m/s for winds less than 25 m/s. This applies for ocean locations greater than 200 km from land having no rain.
3. Water vapor determinations agree very well with radiosondes in Gulf of Alaska and to within 20% in tropics. Wet tropospheric correction for altimeter is accurate to within 10%.
4. Rain has been detected in the data, but quantitative comparisons have not been made because of surface truth data limitations.

Team Members

J. C. Alishouse (NOAA-NESS)	{	- evaluation of atmospheric water determinations
K. B. Katsaros (Univ. of Washington)		
R. L. Bernstein (Scripps Oceanographic Inst.)	{	- evaluation of sea surface temperature determinations
C. Gautier (Univ. of Wisconsin)		
V. J. Cardone (Oceanweather, Inc.)	{	- evaluation of wind speed determinations
T. J. Chester (JPL)		
E. G. Njoku (JPL)	{	
P. W. Rosenkrantz (Mass. Inst. of Technology)		
F. J. Wentz (Remote Sensing Systems)		
T. T. Wilheit (Goddard Space Flight Center)		
B. Wind (JPL)		

## SEASAT SYNTHETIC APERTURE RADAR EXPERIMENT TEAM

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## THE SAR EXPERIMENT

Objectives: The goals of the Synthetic Aperture Radar SAR Experiment are to a) validate the performance of the radar, and b) to apply the results to targets and processes amenable to remote sensing observations and measurements. The purpose is to evaluate the end-to-end SAR system in quantifiable parameters in topical applications carefully selected as applicable to L-band radar measurements and to evaluate the unique characteristics of the radar as function of signature (backscatter) from open oceans, coastal areas, regions covered by ice and land surfaces.

Approach: The strategy adopted for all experiments has been to conduct investigations combining data from the SAR with data from ground-based and aircraft-based measurements wherever feasible. Within each experiment, the approach of investigators is to develop algorithms for merging ground truth with spacecraft sensor data, develop transfer functions that describe the geophysical process observed in terms of the parameters of the SAR, define the backscatter properties of the target area and test the limits of observations and measurements. Because Seasat failed three months after launch, the majority of ground truth experiments did not take place as planned. Hence, the validation of the sensor became primarily focussed on those test sites, in which data were collected during the period of July-September 1978. In other cases, SAR Team members reoriented the objectives of their validation experiments, or relocated them to where data supporting their objectives had been collected independently.

Progress: Validation experiments of the SAR Experiment Team are in various stages of progress. In the case of the Gulf of Alaska (GOASEX) experiment, results on the SAR experiment have been summarized in reports of two workshops in 1979. A symposium on SAR-related results of the East Coast Experiment was held in March 1980. A workshop on the results of the JASIN experiment, including the SAR data, is scheduled for May 1980. Sponsored by COSPAR/SCOR/IUCRM, a symposium will be held in May 1980, in Italy that will report on results of several SAR experiments. An assessment of the engineering characteristics of the SAR, consisting of sensor and spacecraft performance, downlink, station recording and data correlation performance and findings will be held in the autumn of 1980. This activity is critical to the validation experiment results, as investigators are working with correlated SAR data produced by various processors, that have intrinsic differences in performance and products among them. The performance evaluation for the SAR will be followed by topical workshops, colloquia and a symposium on the findings of all SAR validation experiments in early 1981.

### Team membership and experiments:

Robert Beal Applied Physics Laboratory, John Hopkins University  
Bounds of ocean wave detectability, SAR impulse response function

Bruce Blanchard                    Texas A&M University  
Correlation of soil moisture with SAR and scatterometry, watershed  
runoff coefficients

Walter E. Brown, Jr.              Jet Propulsion Laboratory  
Backscatter of geologic targets and surface unit differentiation,  
detection of archaeological sites, geometric fidelity of SAR imagery

William Campbell                 U.S. Geological Survey  
Sea ice dynamics

Frank Gonzalez                 NOAA/Pacific Marine Environmental Lab  
Oceanic currents and Gulf of Alaska waves

J.F.R. Gower                 Institute of Ocean Sciences, Patricia Bay, Canada  
Surface roughness of the ocean due to internal waves

Richard Hayes                 U.S. Coast Guard Oceanographic Unit  
Sea surface targets: iceberg/ship detection

Kumar Krishen                 NASA/Johnson Space Center  
Land/water discrimination, coastal zone and marshlands

Paul LaViolette                 U.S. Naval Ocean R&D Activity  
Ocean front visibility

Alden Loomis                 Jet Propulsion Laboratory  
Geologic structure analysis of folded, faulted sedimentary rocks

Rene O. Ramseier                 Department of Environment, Canada  
Backscatter differentiation of sea ice

Duncan Ross                 NOAA/Atlantic Oceanographic and Meteorologic  
Laboratories  
Gulf of Alaska waves, hurricane waves, and deep-ocean wavelength  
and direction

Clifford Rufenach                 NOAA/Environmental Research Laboratories  
East Pacific wave studies; ionospheric distortion of SAR signals

Omar Shemdin                 Jet Propulsion Laboratory  
Wave studies, Gulf of Mexico, Gulf of Alaska, Bering Sea

John Sherman, III                 NOAA/National Environmental Satellite Service  
Robert Shuchman                 Environmental Research Institute of Michigan  
Ocean currents and refraction of waves; focussing studies on  
SAR processor, lineament detection

V. Roy Slaney                 Geological Survey of Canada  
Geology in the Western Precambrian Shield, N.W. Territories

Robert Stewart                 Scripps Institution of Oceanography  
Waves in JASIN experiments

#### Affiliated experiments:

T.D. Allan Institute of Oceanographic Sciences, U.K.  
Wave spectra, English Channel

W. Alpers Max Plank Institute, W. Germany  
Directional wave spectral analysis and model comparison

M.L. Bryan Jet Propulsion Laboratory  
Hydrology of fresh water lakes, and flooded areas North Slope of Alaska; urban land use

C. Elachi Jet Propulsion Laboratory  
Comparative geologic analysis, Seasat/SIR/aircraft radar data and lineament analysis, volcanic roughness and morphology

A. Fontanel Institut Francais du Petrole, France  
Intercomparison of SAR & SLAR wave data

R. Gedney NASA/Lewis Research Center  
Economical applications experiment

D.G. Goodenough Department of Energy, Mines and Resources, Canada  
Agricultural and forest targets

A. Haskell Royal Aircraft Establishment, U.K.  
Engineering evaluation for applications

J.D. Keppie Department of Mines and Energy, Nova Scotia  
Geology of Nova Scotia

Y.J. Lee Department of Environment, Canada  
Forest land classification and damage

David Lichy U.S. Army Coastal Engineering Research Center  
Coastal waves, offshore North Carolina

A.R. Mack Department of Agriculture, Canada  
Radar reflectance of agricultural crops

R.H.J. Morra DeLoor Physics Laboratory, Netherlands  
Coastal zone processes

K. Rainey Department of Energy, Mines & Resources, Canada  
Calibration the Seasat SAR

G.M. Royer Department of Communications, Canada  
Ionospheric effects of SAR imagery

H. Stewart Jet Propulsion Laboratory  
Geology of mineral deposits

SEASAT VISIBLE AND INFRARED RADIOMETER EXPERIMENT TEAM

Team Leader: Dr. E. Paul McClain, Code S33  
National Environmental Satellite Service, NOAA  
Washington, D.C. 20233  
Telephone: 301/763-8036 (FTS: 763-8036)

Team Members: Mr. Richard Marks, Jet Propulsion Laboratory, Pasadena, Calif. 91103; prepared data processing algorithms and assisted in geophysical evaluation. Dr. Fred Vukovich, Research Triangle Institute, Raleigh, N.C. 27709; assisted in initial geophysical evaluation of data. Dr. Oscar Huh, Coastal Studies Institute, Louisiana State Univ., Baton Rouge, Louisiana 70803; assisted in initial geophysical evaluation. Mr. Andrew McCulloch, NASA Goddard Space Flight Center (Code 941), Greenbelt, Md. 20771; served as Experiment Representative and evaluated instrument performance. Mr. Glenn Cunningham, Jet Propulsion Laboratory, Pasadena, Calif. 91103; assisted in geophysical evaluation.

Experiment Team Objectives, Approach, and Progress: In brief, the objectives of the geophysical evaluation were to ascertain: (1) if the visible and infrared images were of sufficient quality to enable the investigators to locate significant cloud, coastal, and major ocean thermal features; (2) that the noise level in the digital data was sufficiently low to preclude the necessity of excessive spatial smoothing and resultant loss of ground resolution; (3) that the VIRR onboard calibration procedure was available throughout the mission so that biases could be accounted for; (4) that cloud and precipitation diagnostics from VIRR data correlated reliably with the SMMR data where coincident; and (5) that sea-surface temperatures derived from the VIRR correlated highly and consistently with near-simultaneous values derived from VHRR data and/or from comparative shipboard observations.

A preliminary geophysical evaluation of measurements from VIRR was made in conjunction with the first Seasat Gulf of Alaska Experiment (GOASEX) Workshop in Pasadena, Calif., in January 1979. The results of this workshop are reported in detail in a NASA/JPL Doc. 622-101 (April 1979) and have been published in Science (Vol. 204, pp. 1421-24). It was concluded that the VIS and IR images produced from the VIRR are adequate for identification of cloud, land, and water features; and that sea surface temperatures derived for cloud-free areas compared favorably with those that have been obtained by similar infrared radiometers aboard research and operational spacecraft.

A second joint Seasat Workshop was held at the California Institute of Technology, Pasadena, Calif., in June 1979 (NASA/JPL Doc. 622-109, Oct. 1979), and two additional objectives were set forth. One was to explore the use of VIRR data to estimate severe attenuation of SASS (Seasat-A Scatterometer System) signals. The second was to make a comparison of sea surface temperatures (SSTs) derived from the VIRR and scanning multi-channel microwave radiometer (SMMR) in cloudfree or nearly

cloudfree areas; both sets of SSTs were also to be compared with SSTs derived from other sources; e.g., ships, NOAA satellites. The VIRR infrared brightness temperatures were to be corrected for atmospheric attenuation using the SMMR water vapor estimates. Although the results were based on a smaller and less representative data sample than desirable, it appears that a useful relationship exists between SMMR-derived SASS attenuation values and those from VIRR data, especially the high attenuation values. SSTs derived from SMMR were highly correlated with those obtained from analyses by NOAA's National Marine Fisheries Service, but those from the VIRR showed an unexplained negative bias, especially those from northbound passes.

## NIMBUS-7 PROJECT

Point of Contact: Albert J. Fleig, Project Scientist  
Goddard Space Flight Center, Code 910.2  
Greenbelt, Maryland 20771  
301-344-6291

Project Objectives are to observe ocean color, temperature, and ice conditions, particularly in coastal zones, with sufficient spatial and spectral resolution to determine the feasibility of application such as:

- (a) detecting pollutants in the upper level of the oceans,
- (b) determining the nature of materials suspended in the water,
- (c) applying the observations to the mapping of sediments, biologically productive areas, and interactions between coastal effluents and open ocean waters (CZCS),
- (d) demonstrating improvement in ship route forecasting (SMMR).

Nimbus-7 was launched in October, 1978, on a sun synchronous orbit with inclination of 99°, altitude of 938-953 km, and period of 104 min. On the Nimbus-7 two instruments are ocean related, Coastal Zone Color Scanner (CZCS), and Multichannel Microwave Radiometer (SMMR). Both SMMR and CZCS are operating. All data are processed at NASA; SMMR data are archived by NASA; and CZCS data are archived by NOAA. Data retrieval algorithms for both instrument are being developed; their preliminary results are currently being reviewed by NET scientists. All data will be archived for public use as it becomes available.

Additional information can be obtained from the following publications:

Nimbus-7 User's Guide, NASA  
Nimbus-7 Reference Manual, General Electric  
Nimbus-7 Data Application System Data Plan, NASA

Program/project responsibilities include: NASA Headquarters Environmental Observation Division - Program Management, GSFC Orbiting Satellites Project Office - Project Management.

## NIMBUS COASTAL ZONE COLOR SCANNER (CZCS) EXPERIMENT TEAM

Team Leader - Dr. Warren A. Hovis, Jr., NOAA/NESS, S32,  
Washington, DC 20233 Telephone: 301/763-1847

The objective of the Nimbus Experiment Team (NET) has been to determine the accuracy with which the contents of oceanic and coastal waters can be determined by remote sensing of color and temperature from spacecraft altitudes, in order to describe the content of the water in terms of pigment concentration and diffuse attenuation coefficient. The approach has been to carry out oceanographic investigations before and after the launch of Nimbus-7, where optical characteristics were modeled against the content of the water measured by in-situ techniques. Before launch, measurements were made of the upwelled and downwelled radiance in the ocean as a function of depth covering the entire CZCS range, except for the thermal band. Simultaneous measurements were made of the solar insolation at the surface and of transmittance as a function of depth. In-situ measurements were made of content of the water, both organic and inorganic, as a function of depth. These measurements, together with those made of atmospheric transmittance, allowed the NET to develop the algorithm set to remove the effects of atmospheric interference, specifically, to remove both the Rayleigh and the aerosol contribution to the upwelled radiance, and also to remove the Fresnel reflectance component and derive the upwelled radiance as it would be measured immediately below the surface. After launch, six major ship expeditions were carried out in coincidence with overflights of the spacecraft, and simultaneous measurements made for comparison of the calculated results to those measured by the ships. The objective of the NET was to quantify pigment concentration and diffuse attenuation coefficient to an accuracy of  $\frac{1}{4}$  of a log unit, a factor of 2. Comparison of the data measured by the ships with that calculated from the spacecraft data utilizing the algorithms developed by the NET, has shown that the objective has been met and the quantification can be down to within a factor of 2 for both pigment concentration and diffuse attenuation coefficient. Individual team members and their activities are as follows:

Dr. Charles Yentsch, Director of Bigelow Marine Laboratories, West Boothbay Harbor, Maine -- In-situ measurements of biological concentration, determination of phytoplankton species, concentration of inorganic material, and utilization of variance in ratios of CZCS bands to indicate species types.

Mr. Robert Wrigley, NASA/Ames Research Center, Moffett Field, California -- Comparison of CZCS data with measured ship data in Monterey Bay area and modification of the algorithm for the derived product by varying of constants to optimize the model.

Professor Howard Gordon, University of Miami, Coral Gables, Florida -- Leader of the effort to develop the atmospheric correction algorithm, participant in the atmospheric measurements on ship board, analysis of the spectral band selection for possible improvement on future instruments such as the NOSS/CZCS.

Mr. Roswell Austin, Scripps Institution of Oceanography, La Jolla, California -- Leader of the Algorithm Team effort for development of the derived product algorithm after removal of atmospheric effects. Contributor to the algorithm for removal of atmospheric obscuration effects, off-line interactive processing of CZCS data to evaluate the efficiency of the algorithm, and to adjust the algorithm for various ocean conditions.

Mr. Dennis Clark, NOAA/NESS -- Chief Scientist on 3 of the 6 NET expeditions, optical measurements of upwelled and downwelled radiances as a function of depth, atmospheric measurements, and determining the algorithm for extraction of sediment and diffuse attenuation coefficient from ratios of measurements in the CZCS bands.

Dr. Boris Sturm, Joint Research Center, Ispra, Italy -- Coordinator of EURASEP program activity with the NET, leader of the validation effort in 12 European test sites with coincident measurement of CZCS, and evaluation of the algorithm developed by the NET for European waters.

Dr. Frank Anderson, Director, National Research Institute for Oceanology, South Africa -- Validation of the CZCS derived products by comparison with measurements from ships around the coast of South Africa and toward the Antarctic, modification of the NET derived algorithm for optimum results in South African waters.

Edward Baker/John Apel, NOAA/PMEL, Seattle, Washington -- Study of the large scale transport mechanisms of the loop current Gulf Streams, and current off the west coast of the United States by analysis of the derived diffuse attenuation coefficient.

Dr. Warren Hovis, NOAA/NESS, Director, Satellite Experiment Laboratory, Chairman, Nimbus Experiment Team (NET), Washington, D.C. -- Leader of the team, coordinator of the validation effort, coordinator with NASA for the production of the Level 1 and Level 2 data through the NASA processing system, and evaluation of the derived products on a global basis for determination of the value of the CZCS for global water content determination.

**NIMBUS SCANNING MULTICHANNEL  
MICROWAVE RADIOMETER EXPERIMENT TEAM**

**TEAM LEADER:** Dr. Per Gloersen, Code 912  
NASA/Goddard Space Flight Center  
Greenbelt, Maryland 20771

The N-7 SMMR has been acquiring radiometric data from the earth and its atmosphere in ten data channels consisting of both horizontal and vertical polarizations at the wavelengths of 0.8, 1.4, 1.7, 2.8, and 4.6 cm since October 25, 1978. It operates on alternate days: odd Julian days in 1978 and 1980; even in 1979. With some initial difficulties in data aggregation, earth location, and antenna pattern corrections now taken into account to first order, the Team has turned its attention for the time being to testing and refining on an interim basis algorithms for inferring Oceans/Ice parameters from the multispectral radiometric data. These parameters include sea surface temperature, near-surface winds, atmospheric water vapor, cloud water, rain rates, and sea ice concentration, age, and surface temperature. The initial effort involves a two-month global data set (about 800 orbits' worth of data). Preliminary global displays of the geophysical parameters have indicated the appropriate trends, but also some offset in the values, illustrating the need for further adjustment in the calibration of the instrument. After the inferred geophysical parameters have been made consistent with all available surface information (e.g. NOAA buoys, ship reports, and airborne observation experiments) for the two-month data set, a second data set of at least two months will be investigated to confirm the consistency of these interim results. At the same time, an intensive effort is underway to refine the instrument calibration algorithms for the purpose of final validation of the geophysical parameter algorithms.

The experiment team members, each of who work with several associates, are as follows:

F. T. Barath	JPL	Instrument Representative
W. J. Campbell	USGS	Cryosphere Parameters
P. Gudmandsen	Denmark	Greenland Research
K. Kunzi	Switzerland	Snowpack Algorithms
R. O. Ramseier	Canada	Canadian Remote Sensing
D. Ross	NOAA	Ocean Parameters
D. Staelin	MIT	Atmosphere Parameters
T. T. Wilheit	NASA	Ocean/Atmosphere
P. Windsor	Great Britain	European Users

## TIROS-N

PROJECT SCIENTIST: Dr. Albert Arking, Code 915  
ADDRESS: Goddard Space Flight Center  
Greenbelt, MD 20771  
TELEPHONE NO: 344-7208 (FTS)  
Commercial 301-344-7208

### PROJECT OBJECTIVES

1. To provide increased spectral radiometric information for more accurate sea-surface temperature mapping and day/night cloud cover information and to provide higher accuracy and yield of atmospheric temperature and water vapor soundings over the oceans.
2. To provide a remote platform location and data collection capability over the oceans.

### INSTRUMENTATION

1. Advanced Very High Resolution Radiometer (AVHRR)  
This 4-channel scanning radiometer provides stored and direct readout of radiometric data. A fifth channel will be added to increase the accuracy of sea surface temperature measurement in the tropics on later satellites.

2. TIROS Operational Vertical Sounder (TOVS)

This sounder consists of three instruments:

High Resolution Infrared Radiation Sounder (HIRS/2)  
Stratospheric Sounding Unit (SSU)  
Microwave Sounding Unit (MSU)

These instruments will provide better temperature and humidity sounding than previous sounders: The MSU operates well even in the presence of clouds.

### CURRENT STATUS

The TIROS-N was launched on October 13, 1978 and the NOAA-6, its counterpart, on June 27, 1978, and both are presently operating. The TIROS-N is in a 1500 LST ascending orbit while the NOAA-6 is in a 0730 LST descending orbit at the equator. Both are in sunsynchronous orbits at a average altitude of 530 mi. (854 km) with orbital periods of 102 mins for TIROS-N and NOAA-6.

### DATA AVAILABILITY

Data from the AVHRR is available in 4 modes:

1. Direct readout to APT ground stations
2. Direct readout to HRPT ground stations
3. Global onboard recording readout to NOAA-NESS at Suitland, MD
4. Readout of onboard recording selected highest resolution (LAC) data

AVHRR and sounding data is archived at EDIS, World Weather Building, Camp Springs, MD and is available from January to February 1979 on. Both tapes, and picture imagery are available on request.

### ADDITIONAL INFORMATION SOURCES

Satellite Data Users Bulletin (NOAA, EDIS)

Environmental Satellite Imagery (NOAA, EDIS)

NOAA Tech. Memo NESS 107, Nov. 1979 (Data Extraction and Calibration of TIROS-N/NOAA Radiometers)

TIROS-N and NOAA-6 Users Guide (Dec. 1979) (NOAA-EDIS)

Program/Project responsibilities include: NASA Headquarters Environmental Observation Division Program Management, GSFC-Project Management, both in collaboration with NOAA National Environmental Satellite Service.

## NATIONAL OCEANIC SATELLITE SYSTEM (NOSS)

### POINT OF CONTACT:

Gilbert A. Branchflower  
NOSS Project Manager 301-344-5220  
-- OR --  
James L. Mueller 301-344-7895  
NOSS Project Scientist

Code 485  
NASA, Goddard Space Flight Center  
Greenbelt, MD 20771

The NOSS is a limited operational demonstration ocean monitoring mission proposed jointly by NASA, the Department of Commerce (DOC) and the Department of Defense (DoD). Utilizing experience gained from satellite ocean monitoring experiments on Seasat and Nimbus-7, the NOSS will provide the data needed to develop and test new procedures for incorporating routine global satellite observations of ocean parameters into operational weather and oceanographic forecasts. As an additional benefit, the NOSS will also provide a unique satellite data set for oceanographic and climate research.

The NOSS mission is being designed to operationally collect and process ocean satellite data from circa 1986 thru 1991, and deliver it in near real time to its two primary users: the U. S. Navy's Fleet Numerical Oceanographic Center (FNOC) and to NOAA's National Weather Forecast Center and Archive facilities. The Navy will be responsible for further distribution of NOSS data to DoD end users, and NOAA will be responsible for NOSS data distribution to civil end users.

The NOSS spacecraft will carry four primary sensors. These are a radar Scatterometer (SCAT), a radar Altimeter (ALT), a Large Antenna Multifrequency Microwave Radiometer (LAMMR), and a Coastal Zone Color Scanner (CZCS/II). With the exception of the LAMMR, which is a major new sensor development, these instruments are minor modifications of prototype sensors which have flown either on Seasat or Nimbus-7. The oceanographic measurement capabilities which we are at present predicting will be derived from the NOSS are summarized in the attached table.

Currently, NOSS is in an alternate concept study phase, during which several contractors will each propose detailed methods and systems for meeting the overall NOSS objectives and requirements. Assuming that the Congress approves a 1981 Budget New Start for NOSS, one of these contractors will be selected in early 1981 to implement his proposed end-to-end concept for NOSS.

Additional information on NOSS is available in the NOSS Technical Requirements Document, the NOSS Algorithm Development Plan, and other documents which may be obtained from the NOSS Project Office (see above).

NASA responsibilities include: Headquarters Environmental Observation Division - Program Management, GSFC - Project Management.

### Predicted NOSS System Capability

Parameter	Detectable Change	Accuracy	Range	Horizontal Resolution	Instrument
<b>Wind</b>					
Speed	1.5 m/s	±2 m/s or ±10% (whichever is greater)	0 to 50 m/s	17 km*	LAMMR
Speed	1.5 m/s	±2 m/s or ±10% (whichever is greater)	4 to 24 m/s	50 km*	SCAT
Direction	10°	±20°	0 to 360°	50 km	SCAT
Speed (Nadir only)	1.5 m/s	±2 m/s or ±10% (whichever is greater)	4 to 24 m/s	≤12 km	ALT
<b>Sea Surf. Temp.</b>					
Global	1.0°	±1.5°C	-2 to 35°C	25 km**	LAMMR (C-band)
Local	1.0°C	±2.0°C	-2 to 35°C	1.0 km	CZCS
<b>Waves (Sea State)</b>					
Sign. Wave Ht.	0.5 m	±0.5 m or 10%	1 to 20 m	≤10 km	ALT
<b>Ice</b>					
Cover	5%	±15%	0 to 100%	9 km	LAMMR
Thickness	2 m	±2 m	0.25 to 50 m	9 km	LAMMR
Age	New, 1st yr, multi-yr	New, 1st yr, multi-yr	3 levels	9 km	LAMMR
Sheet Height and Boundaries	0.5-m height change	±2-m height change	-5 to +5 m/yr	~10 km	ALT
<b>Water Mass Definition</b>					
Chlorophyll	10% (mg/m <sup>3</sup> )	Within factor of 2	0.05 to 100 mg/m <sup>3</sup>	1.0 km	CZCS
Diffuse Attenuation Coef (k)	10% (m <sup>-1</sup> )	Within factor of 2	0.01 - 6 m <sup>-1</sup>	1.0 km	CZCS
<b>Geostrophic Currents</b>				(length scale)	
Speed	15 cm/s	±15 cm/s	≥15 cm/s	50 km	ALT
Direction	20°	±20°	0 to 360°	50 km	ALT
<b>Water Vapor</b>					
Integrated Atm.	0.2 grams/cm <sup>2</sup>	±0.2 grams/cm <sup>2</sup>	0-6 grams/cm <sup>2</sup>	9 km	LAMMR
Water Vapor Content					

\* 25 km resolution processing will be carried out in storm regions

\*\* Avenues are being explored to significantly improve this resolution.

## TOPOGRAPHY EXPERIMENT (TOPEX)

Charles A. Yamarone, Jr., TOPEX Development Flight Project Manager,  
Jet Propulsion Laboratory, MS 264-420, 4800 Oak Grove  
Drive, Pasadena, California 91103; phone: (213) 354-2144  
or FTS 792-2144.

Robert H. Stewart, TOPEX Development Flight Project Scientist,  
Scripps Institution of Oceanography and Jet Propulsion  
Laboratory, MS 183-335, 4800 Oak Grove Avenue, Pasadena,  
California 91103; phone: (213) 354-5079 or FTS 792-5079.

### Project Objectives

The primary objectives of the experiment are: to employ satellite altimetry of the sea surface topography to monitor the surface geostrophic current over entire ocean basins for several years and to integrate these measurements with subsurface measurements of the ocean's density field in order to monitor the general circulation of the ocean. The ultimate goal of the experiment is to use this information to understand the nature of ocean dynamics, to calculate the heat transported by the oceans, the interaction of currents with waves and sea ice, and to test our ability to predict circulation knowing the forcing of the ocean by winds.

### Instrumentation

The objectives require that the satellite height above the true sea surface be measured and that the height of the satellite above the surface of a calm undisturbed sea be measured. The first measurement is to be made by a satellite-borne radar altimeter of the general type previously flown on Skylab, GEOS III, and Seasat. A dual channel microwave radiometer will gather the information required to correct the altimeter data for atmospheric water vapor. The second measurement will use the results from a laser retro-reflector in combination with laser ground tracking, a Global Positioning System (GPS) receiver, and a three axis accelerometer.

### Current Status

TOPEX is at present in the planning stage as a development flight project. Launch is planned for early in calendar year 1986, based on a FY82 start, with ocean topography data acquisition until 1991. A near-polar orbit is planned to give global ocean coverage. Measurement grid size is planned to be 100 km with a 15 day repeat. Nominal orbit altitude is in the 700 to 800 km range.

### Data Availability

It is anticipated that TOPEX will produce three classes of data: the first includes operational data required for satellite control and a very limited set of raw ocean data which might be

used for coordination of other ocean observations; the second is an interim data record available within weeks of acquisition and containing preliminary corrections; and the third is a full geo-physical record of the data, with all corrections applied, to be available within months of acquisition.

#### Additional Information Services

A major question in the TOPEX development project has to do with the measurement accuracies attainable. The Seasat altimeter data indicates an accuracy of the instrument in the 5 to 10 cm range, but the state of orbit and geoid knowledge during Seasat was in the 1 to 2 meter range. Geoid improvement from Seasat orbit determination efforts currently in progress and from other programs will be required to lower the geoid uncertainties to the 10s of centimeter range, and processing of new data types for orbit determination will be required to achieve similar orbit accuracies. Seasat orbit determination and TOPEX accuracy studies are currently under way.

Program/Project responsibilities include: NASA Headquarters Environmental Observations Division, Oceanic Processes Branch - Program Management, JPL - Project Management.

## A GRAVITY FIELD SATELLITE MISSION (GRAVSAT)

Project Scientist: Dr. David E. Smith, Goddard Space Flight Center,  
Greenbelt, Maryland 20771, Phone: 301-344-8555

Objectives: The determination of the ocean geoid to an accuracy of the order of 10 cm over distances of 100 km and greater, and for the accurate determination of the orbits of altimeter type satellites.

Instrumentation: The proposed system consists of a low altitude satellite (so that it is sensitive to the small scale spatial variations in the earth's gravity field) that is tracked continuously by another satellite. The second satellite is either another low altitude satellite in the same orbit as the first satellite and separated from it by a few hundred kilometers, or a high satellite at a few thousand kilometers altitude. The relative velocities between the two spacecraft are used to derive the earth's gravity field and geoid anomalies. The instrumentation consists of a drag free satellite system on the low altitude spacecraft(s) and a high accuracy satellite-to-satellite tracking system.

Current Status: The mission is in the planning stages with a launch date in the mid-80's. The orbit will be polar, near-circular and at an altitude of 150 to 180 km.

Data Availability: The satellite-to-satellite tracking data will be made available to scientists for their own investigations through an Announcement of Opportunity.

### Additional Information Sources:

Applications of a Dedicated Gravitational Satellite Mission, National Academy of Sciences, Washington, DC, 1979 (avail. Code 921, Goddard Space Flight Center, Greenbelt, Maryland 20771).

Gravsat-A Study Plan, Goddard Space Flight Center, January 1980.

Program/Project responsibilities include: NASA Headquarters Resources Observation Division, Geodynamics Branch - Program Management, GSFC - Project Management.

## GRAVSAT/TOPEX STUDY

DR. William G. Melbourne, Study Leader  
Jet Propulsion Laboratory  
4800 Oak Grove Drive, Mail Stop 264/748  
Pasadena, CA 91103  
Tel: (213) 354-5071; FTS 792-5071

GRAVSAT and TOPEX have a commonality of purpose in that definition and understanding of the geoid is a key ingredient of both. Knowledge of the geoid, such as that to be determined by GRAVSAT, is necessary for full and correct interpretation of TOPEX satellite altimetry. In addition, a geoid determined by GRAVSAT can be augmented by the short-wavelength information derived by TOPEX. Accordingly, to further strengthen the rationale for these programs, the Associate Administrator for Space and Terrestrial Applications (Code E) has requested that a study be undertaken of the advantages and disadvantages of combining these two programs. Specifically, the objectives of the study are to: 1) assess the ability of GRAVSAT to satisfy the ocean geoid requirements of TOPEX, and 2) determine whether or not the scientific commonality is such that a combined program is feasible and justifiable on the bases of data quality, implementation and management considerations, and total program costs.

The major task elements within the study, which is running concurrently with the separate TOPEX and GRAVSAT studies, are:

- 1) Geophysical Product Documentation
- 2) Technology Readiness Assessment
- 3) Performance Prediction Assessment
- 4) Alternate Implementation Concept Development
- 5) Integrated Operation and Facilities Study
- 6) Identification of Preferred Option (2)

The study is sponsored by the Environmental Observations Division and it is to be completed and the results and recommendations reported to NASA-EB by the end of May 1980.

## ICE AND CLIMATE EXPERIMENT (ICEX)

CONTACT: Dr. H. Jay Zwally, Code 912.1  
ICEX Study Scientist  
NASA/Goddard Space Flight Center  
Greenbelt, MD 20771  
301-344-8239 FTS 344-8239

### DESCRIPTION:

The Ice and Climate Experiment (ICEX) is a proposed research program of coordinated investigations of the ice and snow masses of the Earth (the "cryosphere"). These investigations will be carried out with the help of satellite, aircraft, and surface-based observations. Measurements derived from the investigations will be applied to an understanding of the role of the cryosphere in the system that determines the Earth's climate; to a better prediction of the responses of the ice and snow to climatic change; and to studies of the basic nature of ice forms and ice dynamics. Operational techniques will be developed for assisting such activities in the polar regions as transportation, exploitation of natural resources, and petroleum exploration and production.

The principal scientific research problems and the observational requirements concerning terrestrial snow and ice are described in the Report of the ICEX Science and Applications Working Group (GSFC, December 1979). The scientific objective of ICEX is a clearer understanding of the roles of ice and snow in geophysical processes. Special attention will be given to the interactions between the cryosphere and the rest of the planetary system that determine our climate. Answers will be sought to such fundamental questions as: (1) Are the present ice sheets on Greenland and Antarctica growing or shrinking? (2) Are the ice sheets stable or subject to surges? (3) What are the mechanisms associated with the onset of major glaciations and the expansion of seasonal snow cover? (4) What is the quantitative role of sea ice in the climate system? (5) What are the dominant oceanic and atmospheric processes controlling the seasonal growth and decay of sea ice and the interannual variations in ice distribution? (6) What are the relationships between sea ice distribution and ocean circulation? and (7) Can sea ice motion and growth be monitored and forecasted in order to facilitate ocean operations and resource extraction in cold regions? Experiments will be conducted on sea ice dynamics and thermodynamics, ice sheet mass balance, sea ice morphology, regional ice mapping, sea ice forecasting, pressure ridge distribution analysis, ice tracking, and snow mapping.

The key element of the ICEX program will be the spacecraft sensor system, which may be flown on a single dedicated satellite or perhaps on more than one satellite. The sensor system contains six remote-sensing instruments. The Large Antenna Multifrequency Microwave Radiometer (LAMMR) is a passive multichannel radiometer which will image the radiative brightness temperature of the surface in seven microwave bands ranging from 1.4 GHz to 91 GHz (22.4 cm to 0.33 cm). The Wide Swath Image Radar (WSIR) is a X-band (3 cm) synthetic-aperture, side looking radar which produces images of the surface with a pixel size of either 100 m over a 360 km wide swath or 25 m over a 90 km swath. The scatterometer, a side-looking radar, has the capacity to measure the scattering cross section of surface irregularities at 14.6 GHz (2.05 cm). The Ice Elevation Altimeter System (IEAS) is an altimeter system which can measure ice altitude profiles with two complementary instruments: a microwave radar, to provide continuous coverage along the nadir track; and a laser ranging system with commandable pointing, to provide precision altitude determination, offaxis mapping, fine-scale profile resolution, and ranging to reflectors placed on the ice. The Polar Ice Mapping Radiometer (PIMR) is a passive, 5-channel infrared radiometer (4 near-infrared channels detecting reflected solar radiation and one thermal infrared channel at 11  $\mu$ m), which can map cloud cover, determine cloud parameters, measure surface temperatures, and aid in distinguishing surface ice and snow from clouds.

A Data Collection and Location System (DCLS), for locating and relaying telemetry from buoys and other in-situ platforms, is included. Several separate links to site-specific users are included in the ICEX data distribution and relay system. A new link, the Advanced Information Transmission System (AITS) broadcasts WSIR pictures and other data.

An ICEX Data Processing and Analysis Facility (IDPAF) is proposed which will support scientific analysis of ICEX data in near-real time, and will also provide data storage and manipulation capability for longer term research programs. Investigators will gain access to the data by means of an interactive analysis terminal system. In addition to data received from ICEX, the facility will provide direct links to the Climate Data Base and to the Applications Data Service (ADS) for two-way data communication. Raw data, preprocessed data, derived parameters, orbit, and attitude data will reside in the facility data base and will be available instantly to on-line users and to the ADS and Climate Data Base users. Data retransmission from the facility will allow experimental data products to be evaluated for accuracy, timeliness, and application to operational situations. Output data products will also be recorded on film for non-real time scientific analysis and other uses.

ICEX is sponsored by NASA Headquarters Environmental Observation Division, Atmospheric Processes and Oceanic Processes Branches.

## SECTION IV---SENSOR TECHNOLOGY SUMMARIES

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## RADAR ALTIMETRY

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Satellite radar altimetry is devoted to the active remote sensing of the ocean surface and, thereby, represents an important source of measurements. These measurements are sufficient to provide all-weather, independent observations of global topographic features thus contributing to the accurate mapping of underwater features and the detection and measurement of ocean currents, tides, and storm surges, as well as the monitoring of wave height on a global basis.

The basic idea behind altimetry is to utilize the highly stable platform provided by a satellite as a moving reference system from which vertical measurements to the ocean surface are made. Existing altimeter systems essentially provide three measurements:

(1) Altitude - The elapsed time between the time of transmission of an RF pulse of energy to its reception back at the altimeter, after having been scattered from the ocean surface below, is essentially a measurement of the height of the satellite above mean sea level. When merged with accurate orbital information, the results can be related to changes in mean sea level due to such spatially varying quantities as gravity anomalies and such time varying quantities as tides, winds, and currents.

(2) Return Pulse Shape - The slope and time extent of the leading edge of the return pulse can be related to the significant wave height (SWH) of the ocean surface below. Additionally, through a deconvolution process the surface height distribution can be recovered including the skewness thereof. It has been shown that skewness can then be related to such additional oceanographic parameters as dominant wavelength, swell/sea ratio, etc. Finally, the slope and time extent of the

trailing edge of the return pulse can be related to the attitude (angle of the measurement axis with respect to the subsatellite point) of the satellite.

(3) Return Pulse Amplitude - The amplitude of the return pulse, which is determined from the automatic gain control (AGC) used to normalize the incoming waveform, can be related to the backscatter coefficient ( $\sigma_0$ ) of the surface below, which in turn can be related to wind speed over the ocean as well as certain ice related parameters.

The long-term objectives of satellite altimetry were stated in the 1969 Williamstown study on Solid Earth and Ocean Physics. Basically, the development of a satellite altimeter system having a topographic precision of  $\pm 10$  cm or less was called for. It was felt that this level of precision would permit detection of global circulation patterns and greatly augment the scientific significance of all other observations.

The SKYLAB S-193 Altimeter was the first in the series of satellite altimeters that were planned to progressively achieve this goal. This altimeter was designed primarily for obtaining the radar measurements necessary for designing improved altimeters. The GEOS-3 Altimeter, second in the series of satellite altimeters, was launched on April 9, 1975, and was the first globally applied altimeter system. The AAFE Altimeter, an aircraft system which first collected data in October 1975, was a developmental effort directed at bridging the technology gap between the capabilities of the GEOS-3 Altimeter and the rather stringent requirements imposed on the Seasat-1 Altimeter as well as providing surface truth in support of Seasat-1 Altimeter calibration activities. The Seasat-1 Altimeter, third in the series of satellite altimeters, was part of an ocean dedicated satellite instrumentation system and represented the first attempt to achieve 10 cm precision from orbit.

A Seasat class altimeter is one of four primary sensors planned for inclusion on the National Oceanic Satellite System (NOSS), a limited operational demonstration ocean monitoring mission currently planned for launch in 1986. Additionally, an advanced (improved precision, longer life, and possibly having wide swath measurement capability) altimeter system is planned as the prime sensor

for the Dynamic Ocean Topography Experiment (TOPEX), a research mission directed at providing a dedicated capability to globally observe the surface topography of the ocean which, when combined with information on the geoid and oceanic density structure, could provide the absolute geostrophic current structure of the oceans. This mission is presently under study.

The current state-of-the-art in radar altimetry is represented by the Seasat Radar Altimeter. This instrument consists of a 13.5 GHz monostatic radar system that tracks in range only using a one meter parabolic antenna pointed at the satellite nadir. One of its unique features is the microprocessor implementation of the closed loop range tracking, automatic gain control (AGC), and real time estimation of SWH. Additionally, a linear FM transmitter with 320 MHz bandwidth yields a 3.125 nano-second time delay resolution. This high resolution, coupled with a high transmitted pulse rate of 1020 Hz, permits the realization of the desired 10 cm altitude precision.

An evaluation of the data acquired by Seasat has shown that the Seasat Altimeter generally performed in accordance with its original performance requirements of measuring altitude to a precision of less than 10 cm RMS, significant wave height to an accuracy of  $\pm 0.5$  m or 10% whichever is greater, and ocean backscatter coefficient to an accuracy of  $\pm 1$  db, all over an SWH range of 1 to 20 meters. These measurements are provided at a nominal rate of 10/S with a nominal measurement footprint diameter of 1.6 km centered on the nadir. The resulting data rate is approximately 8.5 KBPS.

While the Seasat class altimeter is considered to be operational with respect to remote sensing of ocean parameters, there are a number of improvements to this system that are under study. Some of these are:

- 1) Adaptive Resolution: This scheme would sense return signal shape and duration changes resulting primarily from surface slope variations over ice and adaptively select resolution such that the total return falls within the tracking window, thus, allowing continuous data over ice to be obtained.

2) Multi-Beam Interferometer: This scheme would utilize an interferometer technique to generate multiple beams displaced cross track by equal angles such that three independent altimeter height measurements equally spaced across a 100 km swath would be obtained thus allowing for more rapid mapping of ocean current features.

3) Improved Precision: To satisfy the requirements associated with TOPEX, the detection of changes in surface topography due to ocean currents to the 1-2 cm level for SWH less than 5 m will be required. Over this range of SWH, the present Seasat class altimeter is considered to have a basic instrument precision of 3-6 cm. The required 3:1 improvement can be provided through some reasonable combination of wider transmitted bandwidth, higher PRF, or possibly, some form of frequency or spatial independence.

Optimally, these advanced altimetry concepts should be implemented and evaluated on one or more shuttle sortie flights prior to committing to their implementation on a free-flying satellite such as TOPEX. The feasibility and desirability of doing this is presently under study.

## MICROWAVE SCATTEROMETRY

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A microwave scatterometer is a special purpose radar which performs a quantitative measurement of the backscattered power from a target surface. Through the radar equation, this measurement is used to calculate the scattering coefficient  $\gamma$  or the normalized radar cross section  $\sigma^0$  of the surface. These quantities are essentially the radar reflectivity of the surface normalized on a per unit area basis and differ by the  $\cos \theta$  where  $\theta$  is the incidence angle (angle between propagation direction and local surface normal). The radar reflectivity is itself a function of the electromagnetic wave polarization, incidence angle, and the roughness and the complex dielectric constant of the surface.

Thus the scatterometry technique for inferring geophysical parameters relies on the correlation of the roughness and dielectric properties of the scattering surface with the desired parameter. Scatterometers have been shown to be useful for inferring parameters of the atmosphere, land, ocean and ice. Since this annual report deals with only the oceanic processes program, only the latter two applications will be discussed.

For the oceans, the scatterometer measurement is divided into two regimes of interest; incidence angles near-nadir and those well off-nadir. Near nadir, the  $\sigma^0$  has been shown to be dependent on polarization and a function of the RMS slope of the surface (contributed by ocean waves from cm to 100 m lengths). Because of this large range of influencing ocean wavelengths, the RMS slope is correlated to both sea state and wind speed. Off-nadir, the  $\sigma^0$  is, to the first order, proportional to the height spectrum of Bragg scatterers (short gravity and capillary waves) and is a function of the EM polarization. Because of the strong correlation between capillary waves and surface winds, the scatterometer is useful for inferring wind vector over the ocean.

An algorithm for converting multi-azimuth look radar measurements into friction velocity  $\bar{u}_*$  and neutral stability wind vector  $\bar{u}_{19}$  has been developed for the SeaSat program. On a scale of understanding from zero to ten (zero = no understanding, ten = fully understood), the maturity of this algorithm is 7-8. Remaining questions are concerned with the correlation of the amplitude of the Bragg scatterers with wind stress, momentum flux, drag

coefficient, etc., and the influence of other parameters such as sea state, spray and foam, currents, sea surface temperature, atmospheric stability, etc. It is our plan to address these questions through analysis of SeaSat scatterometer data and by conducting comprehensive field experiments using airborne scatterometers, imaging radars and passive microwave systems. It is envisioned that this SR & T will improve the wind vector algorithms proposed for the National Oceanic Satellite System (NOSS) Scatterometer.

For ice, the scatterometer measurement is less well understood. Data exist for ground based and airborne systems which demonstrate that the scatterometer responds to roughness (ridging, rafting, etc.), age (first-year vs multi-year) and thickness for thin ice (LIM); however, for a single radar measurement, the value of  $\sigma^0$  are not unique for these ice parameters. Multipolarization and incidence angle measurements will aid in removing this ambiguity, but we feel a better approach is the combined use of multi-frequency microwave radiometers and a single frequency scatterometer. It is our plan to analyze existing aircraft and satellite (SeaSat) data to develop an ice interpretation algorithm using combined active/passive microwave measurements. It is estimated that the present state-of-the-art is 3-4 on the understanding scale, but it is anticipated that this situation will improve significantly over the next 3 to 5 years.

## SYNTHETIC APERTURE RADAR (SAR)

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A synthetic aperture radar (SAR) is a special type of coherent imaging radar that produces fine resolution two-dimensional images. In its usual form, the radar is transported by means of an aircraft or satellite while illuminating a strip of the earth's surface that is parallel to the flight path. As a result of the forward motion of the radar vehicle, the antenna beam scans the strip in the along-track (azimuth) dimension. The resulting SAR image is a two-dimensional map of the backscatter reflectivity properties of the terrain strip as illuminated at the radar wavelength. An important feature of SAR imaging systems is that they can operate in the microwave region of the electromagnetic spectrum and, hence, can observe the earth both day and night and can penetrate clouds and moderate amounts of precipitation.

The unique characteristic of SAR systems is the data processing that produces the equivalent effect of an extremely long antenna which expands in length in direct proportion to radar range. This provides a resolution in the azimuth direction that is constant for all ranges. In a conventional radar, the azimuth resolution at any range is determined by the azimuth dimension of the physical antenna beam measured at that range. Since the antenna beam width is inversely proportional to the antenna size, prohibitively large antennas would be required to achieve fine resolution at long ranges. The synthetic aperture technique implies that a relatively small antenna is carried by a vehicle to a sequence of positions that would be occupied by individual elements of a long linear array antenna. Storage and coherent combination of successive radar echoes are the key operations in the array-forming process. The storage of the radar returns can be implemented either optically or digitally. This recorded data, which is referred to as the Doppler phase history, must then be processed (optically or digitally) to obtain an image of the terrain. Typically, this processing is performed on the ground after data collection, although recently, real time airborne digital processing has been demonstrated. The SAR principle allows one to achieve extremely fine azimuth resolution images with real antenna aperture very much smaller than required for conventional radars. Fine resolution in the range dimension is achieved either by transmitting short duration pulses or made typically by using large bandwidth pulse compression techniques.

The reflectivity map produced by the SAR contains information dealing with both the roughness characteristics as well as the electromagnetic properties of the imaged area. In addition, since the synthetic aperture process inherently utilizes the variation in Doppler velocity as a function of azimuth position across the antenna beam, any motion of the scattering surface, e.g., ocean-waves will affect the image. Many other radar and data processing parameters will also influence the image and must be considered during the interpretation process. These include: radar wavelength, transmit and receive polarizations, range and azimuth resolution, illumination aspect angle, non-coherent integration factor, image projection plane, signal-to-noise ratio, etc.

Since SAR's were developed in the 1950's, there have been many significant military and (more recently) civilian applications. SAR systems have been developed to operate at wavelengths ranging from 60 meters to nearly optical wavelengths with X-band (approximately 3 cm) and L-band (approximately 25 cm) being the most common. The SAR vehicle is typically an aircraft, e.g., the UPD-4 is an operational U.S. Air Force X-band SAR carried by an F-4 and the ERIM designed 4-channel SAR operates at X- and L-band with two polarizations and is currently carried by a Canadian owned CV-580. There are other SAR's flown on aircraft by both industry and government, the Goodyear X-band and JPL L-band being examples. Previous non-aircraft examples as an L-band SAR was part of the five sensor package on SEASAT and a three-wavelength SAR operating at 60, 20, and 2 meters which was used in the Apollo 17 Lunar Sounder Experiment. Aircraft SAR's often have resolutions of a few meters with range swath widths up to 50 km. Data are recorded and processed both optically and digitally and real time ground-based and on-board processors have been developed. Satellite SAR's, like the one that was flown on SEASAT, have resolutions on the order of 25 meters and swaths of approximately 100 km. A satellite SAR is typically single frequency and polarization due to data rate considerations. Future proposed SAR satellite systems include the shuttle imaging radar (SIR-A), the shuttle reflight SAR, ERSAR, and ICEX. Only the shuttle SAR's are funded programs and their orbits are limited in terms of polar coverage.

Sensor performance evaluation of the SEASAT SAR is not complete at the present time. A series of SEASAT SAR experiments are being conducted to validate the instrument in respect to the detection of: (1) deep and shallow water gravity waves, (2) wind fields, (3) internal waves, (4) currents, (5) ships and icebergs, (6) ice types, (7) ice dynamics, and (8) frontal features. A partial engineering evaluation was also conducted on the SEASAT SAR to determine resolution, dynamic range, signal to noise, and image ambiguities.

The SEASAT SAR's primary purpose was to image gravity waves in both coastal and deep water. Radar oceanographers are in general agreement that SAR can successfully image gravity waves that are traveling within 25° of range. Principally, only swell imaged by the SEASAT SAR was compared favorably (direction  $\pm 15^\circ$ : wavelength  $\pm 15$  meters) to sea truth. The question of determination of dominant wavelength and direction regardless of radar look direction has not been fully studied.

The SAR community is in general agreement that the principal reflectivity mechanism of the SAR and the ocean surface is via the capillary or small (1-30 cm) gravity waves. The reflectivity of a large area of sea surface observed by a SAR provides an apparent brightness that approaches a Bragg-Rice reflectivity model. Although the SAR image intensity is a result of the capillary and small gravity waves, it appears to also successfully image larger scale ocean features such as gravity wave fields, internal waves, and ocean frontal features. Ships, ice fields and icebergs are also successfully imaged by the SAR in part due to specular reflections from these features. To summarize, SAR has the potential to yield information on both the small and large scale surfaces of the oceans.

Various problems are associated with the use of SAR for ocean surface measurements. To date, a complete theory to explain the EM interaction of the SAR with the capillary and long gravity waves is not totally understood. The effects of ocean wave motion, as sensed by the Doppler sensitive SAR, needs to be better quantified. An algorithm to detect ocean currents and gravity wave height needs to be perfected. The SAR sensor itself has a tremendous data rate (20 megabit for SEASAT). Methods need to be explored to better handle these data rates, display and store this data. The SAR radar backscatter values of ocean surface have been related to wind and air/sea temperature differences. The problem to date has been in the calibration of the  $\sigma_0$  values. The SEASAT SAR was not calibrated and as such the wind dependence on  $\sigma_0$  is hard to quantify. An additional problem with wind speed determination is sorting out the directional sensitivity. The above question should be explored in future SAR ocean experiments.

## MICROWAVE RADIOMETRY

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Microwave Radiometry is the measurement of thermally emitted microwave radiation. Only the frequency range from about 1 to 40 GHz (30 cm to 0.7 cm) is of interest for oceanographic applications. In this frequency range and for typical terrestrial temperatures the Rayleigh-Jeans approximation to the Planck blackbody radiation law works extremely well and thus the radiation intensity is proportional to the absolute temperature of the emitter. This intensity is characterized as a brightness temperature,  $T_B$ , which is the thermodynamic temperature required for a blackbody to emit a given intensity of radiation. In the frequency range of interest here, the brightness temperature which would be observed upwelling from the Earth by a radiometer in an aircraft or spacecraft is given by  $T_B = ET_S + A$  where  $T_S$  is the thermodynamic temperature of the surface,  $E$  is the emissivity of the surface and  $A$  represents atmospheric corrections. The emissivity is a quantity between 0 and 1 which depends on the viewing parameters (frequency, polarization, viewing angle) which are under the control of the instrument designer and on surface properties (composition, temperature, structure) which include the information being sought. In particular, the emissivity of sea water is typically in the range 0.3 to 0.7 and in addition to the viewing parameters is dependent on the temperature and salinity of the water and on the surface structure (roughness, foam) which is, in turn, largely determined by the wind stress at the surface.

Solid surfaces, such as land and sea ice, on the other hand, typically have emissivities greater than 0.8. Moreover, the internal structure of sea ice affects its emissivity such that there is a marked emissivity difference between first year and multi-year sea ice.

The atmospheric correction term also depends on the viewing parameters and on the water vapor and liquid water content of the atmosphere. Water vapor has a rather weak but broad resonance centered at 22.235 GHz and many strong ones at 183 GHz and beyond the wings of which become important above 30 GHz. Liquid water, in the form of small droplets found in non-precipitating clouds, has an effect on the brightness temperature approximately proportional to frequency squared. Rain, on the other hand, has a large and complicated effect on the brightness temperature and it

is no longer reasonable to treat the atmosphere as a minor correction to surface observations in the presence of rain.

There have been (or will be) a number of spaceborne microwave radiometers with oceanographic applications. They will be treated individually and chronologically.

Electrically Scanned Microwave Radiometer Nimbus-5 Satellite (ESMR-5): The Nimbus-5 satellite was launched December 11, 1972, into a near-polar sun-synchronous orbit. The ESMR aboard this satellite scanned a swath approximately 2500 km wide mapping the microwave brightness at a frequency of 19.35 GHz with a resolution (at nadir) of 25 km. Since the measurements were only at one frequency there is no way to separate the various effects determining the microwave brightness. Meaningful interpretation is only possible when one effect dominates the situation so that the others may be ignored. One such application is the measurement of rain intensity over the ocean. In spite of various problems, the ESMR-5 data have provided the best available estimates of rain rates over the entire world's oceans.

The relative dryness of the polar atmospheres makes interpretation of ESMR-5 data in terms of the boundary, concentration and type of sea ice possible. In spite of degraded instrument performance, the US Navy still uses ESMR-5 as the primary data source for its operational ice analyses.

Nimbus-6 Electrically Scanned Microwave Radiometer (ESMR-6): Nimbus-6 was launched June 11, 1975. The ESMR aboard this satellite scanned along a cone with a quasi-vertical axis so that the beam intersected the earth at  $50^\circ \pm 1^\circ$  throughout the scan. It measured the microwave brightness at 37 GHz in two polarizations. The data have been used to investigate the effect of wind on the roughness of the ocean surface. The data are, in principle, useful for mapping sea ice coverage and for identifying first and multi-year ice.

The instrument was operated approximately  $\frac{1}{2}$ -time from June 1975 to June 1976. It was operated fulltime from June 1976 to September 1976 at which time the horizontally polarized channel failed.

Scanning Multichannel Microwave Radiometer (SMMR), Seasat & Nimbus-7: The SMMR is a five-frequency (6.6, 10.7, 18, 21, 37 GHz) dual-polarized microwave radiometer wherein all five frequencies have a common 80 cm aperture. The scan is conical so that all the beams have a constant incidence angle. The resolution varies inversely with frequency from about 150 km at 6.6 GHz to 30 km at 37 GHz.

Identical copies of the SMMR were launched on Seasat and Nimbus-7. Seasat was launched in June 1978, and failed in October 1978; Nimbus-7 was launched in October 1978.

The primary objective of the instrument is the measurement of sea surface temperature and wind speeds. As a first attempt to verify all the Seasat measurements including SMMR, JPL held a workshop in January 1979. They found large biases in the retrieved values which depended on scan position but, when these were removed, they found sea surface retrieval accuracy of the order  $1.5^{\circ}\text{C}$  and wind speed error of the order 2.5 m/s. Subsequent workshops found that the retrievals did not always work this well and a "good rev"/"bad rev" distinction was developed, which was traced to a programming error in the calibration routine. It is thought that all data will be "good revs" now but the upcoming JASIN (Joint Air-Sea Interaction) workshop to be held in Pasadena, California, should confirm this. Approximately 400 minutes of data have been processed for this workshop.

Validation efforts for the Nimbus-7 SMMR have lagged somewhat behind the Seasat effort, but recently a 2-month data set has been generated (November 1978, February 15-March 15, 1979). The brightness temperatures have been converted to geophysical units for the first 6 days. Global maps of these parameters appear reasonable but show identifiable and correctable problems.

Large Antenna Multifrequency Microwave Radiometer (LAMMR):

According to present plans, subject to Congressional approval, the first National Oceanic Satellite System (NOSS) satellite will be launched in 1986. A key instrument will be the LAMMR which will be similar to the SMMR which was flown on Nimbus-7 and Seasat, except that the larger antenna will provide greatly improved spatial resolution and cleaner design will permit more accurate measurements. The frequencies are basically the same as SMMR except that a channel at 4.3 GHz has been substituted for the one at 6.6 GHz in an effort to mitigate the effect of manmade radiation (RFI). The instrument should yield sea surface temperatures with a resolution of 36 km and an accuracy of  $1^{\circ}$  rms. The wind speed determination should have a resolution somewhat better than 20 km and an accuracy of better than 2 m/s. The addition of channels at 5.1 and 6.6 GHz to give sea surface temperature data at resolutions of 30 and 25 km, where RFI conditions permit, is under active consideration.

## INFRARED RADIOMETRY

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Although there were some early demonstrations of satellite-derived surface temperatures using TIROS II infrared measurements, the first good opportunity for exploring this capability of deriving sea-surface temperatures from space was provided by some of the early Nimbus and METEOR meteorological satellites after about 1966. The Nimbus series was the first to carry high-resolution (8 km), scanning infrared radiometers. Although these data were extremely "noisy", it was possible to detect in a crude way the main features of strong thermal fronts, such as those associated with the Gulf Stream. These data also served as a basis for the first attempts to develop statistical methods of spatial and temporal compositing of infrared (IR) measurements for the purpose of cloud-filtering and global temperature mapping. In 1973, experimental operational production of global sea surface temperature charts (100 km grid) commenced on a daily basis.

The NOAA series consisted of Improved TIROS Operational Satellites (ITOS), which were placed in circular, near-polar, sun-synchronous orbits above the Earth at a nominal altitude of 1450 km. Each ITOS was equipped with two types of radiometers. The first is the Scanning Radiometer (SR), a dual-channel, line-scanning radiometer that measures reflected solar radiation in the 0.5-0.7 $\mu$ m range and emitted infrared radiation in the atmospheric "window" region (10.5-12.5 $\mu$ m). The instantaneous field-of-view of the visible channel is such that ground resolution of the data at nadir was about 4 km; the corresponding value for the thermal infrared (IR) channel data was about 8 km. Provision was made for the radiometer to view reference-level targets for sensor calibration.

The second type was the Very High Resolution Radiometer (VHRR), which was designed primarily for local direct broadcast of data, and whose chief use has been for non-meteorological purposes, e.g., for oceanographic and hydrologic applications. The VHRR was similar in many ways to the SR, being a two-channel, line-scanning radiometer sensitive to energy in the 0.6-0.7 and 10.5-12.5 $\mu$ m bands. The VHRR, however, had substantially better ground resolution than the SR, i.e., about 1 km at nadir for both channels. Calibration arrangements were similar to those for the SR. Both SR and VHRR were transmitted in analog form from the spacecraft; digitization, if desired, had to be accomplished on the ground.

The first in the third generation of USA polar-orbiting operational environmental satellites was launched in October 1978, and the second was placed in orbit in April 1979. The NASA prototype of this series is called TIROS N, but subsequent NOAA-funded satellites will be called NOAA-6, NOAA-7, etc., because

NOAA-5 is the number of the last spacecraft in the ITOS series. The major improvements that TIROS N brought include the replacement of the SR and the VHRR by the Advanced Very High Resolution Radiometer (AVHRR) and digitization by an onboard data processor. The spectral characteristics of the TIROS N/NOAA AVHRR instruments is given in the table below:

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Four-channel AVHRR, TIROS N

Ch 1	Ch 2	Ch 3	Ch 4	Ch 5
0.55-0.9 $\mu$ m	0.725-1.1 $\mu$ m	3.55-3.93 $\mu$ m	10.5-11.5 $\mu$ m	Data from Ch 4 repeated

Four-channel AVHRR - NOAA-A, -B, -C, and -E

Ch 1	Ch 2	Ch 3	Ch 4	Ch 5
0.58-0.68 $\mu$ m	0.725-1.1 $\mu$ m	3.55-3.93 $\mu$ m	10.5-11.5 $\mu$ m	Data from Ch 4 repeated

Five-channel AVHRR, NOAA-D, -F, and -G

Ch 1	Ch 2	Ch 3	Ch 4	Ch 5
0.58-0.68 $\mu$ m	0.725-1.1 $\mu$ m	3.55-3.93 $\mu$ m	10.3-11.3 $\mu$ m	11.5-12.5 $\mu$ m

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The ground resolution for all channels of the AVHRR is 1.1 km at nadir. The window channels have a NEAT. $<0.12$ K at 300K, whereas the visible and reflective infrared channels have a S/N of 3:1 at 0.5% albedo.

In the daytime the first two channels of AVHRR can be used to filter cloud-contaminated infrared measurements, and the third channel (10.5-11.5 $\mu$ m) can be used for the actual surface-temperature computation. The fourth channel (3.55-3.93 $\mu$ m) cannot be used in the daytime because of severe contamination by reflected solar energy, but it should be superior to the third channel at night for two reasons: (1) much less water vapor attenuation; and (2) much more effective suppression of the effects of clouds that only partially fill the field of view of the radiometer. Furthermore, the difference between the 3.7 $\mu$ m and 11.0 $\mu$ m window channel brightness temperatures tend to be large and positive for middle and high clouds in the field of view, principally because cloud emissivities at 3.7 $\mu$ m are significantly less than unity.

The physical basis of remote sensing of ocean temperature is, in the simplest terms, the detection and measurement of the Earth and atmosphere's radiative emission by a radiometer carried onboard a ship, an aircraft, or a spacecraft. Radiation laws are used to determine the effective brightness temperature of the emitting substances.. The physical temperature of the ocean surface can be calculated from the brightness temperature by knowing the spectral emissivity of sea water (near 1.0 in the range 8-12 $\mu$ m) and correcting for attenuation and emission of the atmosphere. Onboard thermal calibration is usually

accomplished by having the radiometer frequently view both a known cold reference (viz., deep space) and a known warm reference (viz., the housing of the radiometer, whose temperature is monitored by means of thermistors).

The effect of the intervening atmosphere on satellite-derived brightness temperatures in the 10.5-12.5 $\mu$ m "window" region is to lower them by a few tenths of a degree Kelvin in very cold and dry atmospheres to nearly 10°K in very warm and moist atmospheres. In the 3.7 $\mu$ m window the corresponding corrections for the atmosphere are about half as large. There are several methods that have been employed to make atmospheric corrections. The simplest, and least accurate in most cases, is one in which a theoretical correction is derived from a set of model atmospheres. Current operational procedures at NOAA/NESS make use of coefficients derived from HIRS (High Resolution Infrared Sounder) processing of coincident satellite temperature and water vapor soundings. Another method required knowledge of water vapor distribution in the vertical and horizontal inferred from conventional radiosonde measurements. If two or more IR detectors, each sensitive in a different and unequally transparent part of the water vapor window(s), view Earth's surface simultaneously through the same atmospheric column, then the differences in their measured brightness temperatures provides an atmospheric correction to one or the other of the temperatures.

Studies have shown that relative temperature differences between ship and satellite temperatures range from about 0.5° to 1.5°C RMS (root mean square). Absolute temperature accuracy depends on the accuracy of the atmospheric correction, which in turn depends chiefly upon knowledge of the water vapor content of the atmosphere and whether the radiometer scan-spot was free of clouds. Under the best of conditions the absolute temperature differences (RMS) between ships and satellite range from about 1.0° to 2.0°C. However, virtually all ship-measured temperatures are thermal equilibrium temperatures rather than radiative, and are bulk rather than skin temperatures. Studies have shown, however, that the differences between skin and bulk temperatures are generally much smaller than the errors cited above.

Simulations of the multiple-window channel method for atmospheric corrections, which used a geographically and seasonally diverse set of radiosonde observations and calculated brightness temperatures, indicate that this technique is superior to previously used ones. This approach is to be further developed and tested with nighttime TIROS N measurements from the third and fourth channels of AVHRR. This method of making atmospheric corrections can be extended to daytime observations when the fifth channel is added to later spacecraft of the TIROS N series. Meanwhile one can utilize the visible channels of AVHRR in the daytime to screen out infrared observations with low cloudiness.

## OCEAN COLOR RADIOMETRY

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Ocean color radiometry is the measurement of solar radiant energy backscattered from the photic zone of the ocean's surface layer. During the last ten years, there has been a concentrated effort to demonstrate the feasibility of remotely sensing the constituents of the surface layer of the ocean via this measurement technique. Comparison of near-surface radiometry, from both aircraft and ships, with traditional in-situ measurements of concentrations of these constituents has shown good correlations for those waters in which biological constituents are dominant. However, extrapolation of this technique to spacecraft altitudes is complicated by the intervening atmosphere. The radiant energy detected by the spacecraft sensor is dominated by photons backscattered from the atmosphere. The Rayleigh component of this signal can be calculated, but determination of the aerosol component requires considerable ingenuity. Additional complications in the interpretation of the ocean color data arise from sunglint, the specular reflection of the incident solar radiation off the ocean surface and into the sensor aperture; the reflections from foam, which are spectrally indistinguishable from sunglint; and, in near coastal waters, the additional signal from suspended sediments.

Examination of the spectral response of both the oceanic constituents and the sources of interference have led to the selection of spectral channels which, after incorporation in the remote sensing hardware, produce signals which are used to generate images of chlorophyll concentration and the diffuse attenuation coefficient. The present status of the ocean color algorithms using data from both high altitude aircraft and the Nimbus-7 Coastal Zone Color Scanner (CZCS) is as follows:

- (1) Atmospheric corrections for both the Rayleigh and Mie components are quite adequate when normalized by a surface measurement taken within the image being processed and show promise of working well without normalization.
- (2) Images of chlorophyll concentration using data acquired above the atmosphere have shown good correlation with in-situ measurements over a wide range of concentrations (0.1-70 microgram/liter) and a wide variety of

oceanic waters.

Imagery analyzed to date, has been selected to avoid areas with large amounts of sunglint, foam, and suspended sediments. Preliminary work to correct for these parameters shows promise but has got to be demonstrated. Likewise, measurements of the diffuse attenuation coefficient are proceeding well but this data has yet to be placed in the open literature.

Until the launch of the Nimbus-7/CZCS in October 1978, ocean color data was acquired via medium and high altitude airborne sensors. The CZCS is a 6-channel, visible and infrared, scanning radiometer designed to measure images of radiance upwelled from the ocean in the following wavelength bands:

<u>Channels</u>	<u>Wavelengths</u>
1	433-453 nm
2	510-530 nm
3	540-560 nm
4	660-680 nm
5	700-800 nm
6	10.5-12.5 um

The CZCS has an average resolution of approximately 1 km over a 1500 km swath. The sensor is performing well with the exception of channel 6 which failed in late 1979. A large amount of calibrated data is expected to be available for distribution by the end of 1980.

The next ocean color experiment from space will be the Ocean Color Experiment (OCE) aboard Shuttle/OSTA-1 in early 1981. The OCE is an 8-channel modification of a high-altitude airborne sensor that will be used to develop additional atmospheric correction algorithms utilizing the data from four channels in the near-infrared.

The National Oceanic Satellite System (NOSS) slated for a 1986 launch will include the CZCS-2, a 9-channel version of the Nimbus/CZCS. The major improvement provided by NOSS will be near-real-time delivery of chlorophyll and diffuse attenuation coefficient images to the users.

## NEW SENSOR CANDIDATES

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With the demise of the AAFE program, and the cutbacks in instrument related SR&T due to Seasat, the development of new and improved instrument technology related to remote sensing of the world's oceans has been slowed down considerably. The result of this is that ocean remote sensing technology is, for the most part, 5 years or more old. In this regard, a survey of the instrument development community was conducted this past fall (1979) relative to defining a shuttle based oceanographic instrument technology development program that takes maximum advantage of the shuttle sortie mode of operation and supports NASA's Oceanic Processes program.

The Shuttle/Spacelab concept gives NASA a new capability for satisfying user needs relating to Oceanic Processes. There are a number of types of activities that could benefit from the shirt-sleeve environment and the capability to return a payload to earth for subsequent modification and reflight. Specifically, new instruments and measurement techniques could be evaluated relative to providing new, or more accurate, or more precise measurements of variables important for the study of processes at work within or on the surface of the world's oceans.

This would be accomplished using a balanced mix of theoretical studies, instrument and algorithm development, lab and aircraft tests, and culminating in final checkout and assessment on shuttle prior to consideration for inclusion on future earth-orbiting oceanographic missions. Additionally, out of this process would come a set of shuttle compatible measurement systems that could be used both to support specific oceanographic experiments and programs, and to respond

to predictable (e.g., seasonal or local) targets of opportunity.

Resulting from the survey were a total of 40 proposed activities relating to oceanographic instrument development. Of these, 31 represented improvements and/or modifications to, or involving existing sensors. The other 9 essentially represented new sensor concepts. A number of the proposed activities are already at some stage of development although none are currently funded through shuttle check-out and assessment. Examples of some of the more promising development activities are:

1) A versatile radar altimeter system was proposed that would incorporate a number of advanced altimetry concepts. The heart of this system would be the Seasat Engineering Model Altimeter residual hardware modified in an appropriate manner to accomplish the desired objectives. The general philosophy would be to provide the capability to test and evaluate from space those proposed techniques that are intended to address the problem of mapping the polar ice sheets, provide the precision and coverage required to study global circulation patterns, provide an improved capability for measuring wave related parameters, and in general provide for all-around improved performance.

2) The development of a salinity measuring radiometer system for the study from space of salinity patterns in coastal water and salinity variations across oceanic fronts in the open ocean was proposed. This has not previously been pursued due to problems in achieving reasonable spatial resolution with acceptable accuracy. By using a 10 meter antenna (which would be feasible for deployment during a Shuttle sortie mission), a spatial resolution at L-band of 20 km could be obtained. The expected accuracy would be of the order of  $\pm 0.2$  part per thousand. While the spatial resolution would not be as good as desired, a shuttle experiment built to these requirements would clearly demonstrate the feasibility of measuring salinity from space with the required accuracy and stability. Once that is done, the shuttle capability could then be used to erect a larger antenna (to obtain the required spatial resolution of a few km) on a free-flying version of the system.

3) Obtaining a topographic map of the Antarctic and Greenland ice bottom would be of considerable interest in determining the volume of ice on those continents. In this regard, a Shuttle borne VHF sounder was proposed which could provide ice coverage with 20 km grid spacing, footprint resolution of a few kilometers cross-track and a few hundred meters along track, a height resolution of 10 to 100 meters depending on the bottom topography, and a sounding capability through up to 4 km of ice. Global, synoptic coverage could be obtained during a single shuttle flight. A radar altimeter could also be included to provide surface topography with about 1-2 m accuracy and 10-50 cm resolution.

4) A rather novel way of obtaining localized in-situ accurate measurements of wave spectra with a near global distribution was proposed. Utilizing a near earth orbiting VHF (approximately 50 MHz) dual frequency transmitter having HF separation (5 MHz or so), this system would take advantage of the Bragg scattering properties of ocean waves to determine the wave spectrum around a receiving site (10-20 km coverage) when the satellite passes overhead while radiating towards the ocean surface. This is an updated version of the old bistatic radar. The feasibility of this technique could be evaluated from an aircraft.

5) A scanning laser ranging system was proposed that could provide fine scale, high resolution topographic mapping of the ice surface as well as ranging to fixed retroreflective targets for the purpose of precision orbit determination and/or measuring ice sheet motion. Additionally, when operated simultaneously with a radar altimeter system, it could provide a calibration of that system as well as providing a measurement of ionospheric and wet tropospheric losses. Under microprocessor control, a short pulse ND:YAG laser would transmit 10-20 pulses per second to the surface and using the scanning capability, to retroreflective targets at known locations, while providing an overall ranging accuracy of 5-10 cm. This system has great promise, particularly in the area of precision orbit determination.

These, and others, are currently under consideration for further development. In some cases, feasibility studies need to be conducted to better define a particular con-

cept or to better justify its need. Final selection of the activities to be fully developed will depend on the results of both the feasibility studies and the availability of the necessary funding.

SECTION V---INDIVIDUAL PROJECT SUMMARIES

Summaries of individual research projects are given on the following pages, alphabetically according to the name of the senior principal investigator. Included in this section are 22 investigations which are supported under the NOAA/NASA Seasat Announcement of Opportunity, for which contracting services are provided by NOAA.

## GREAT LAKES REMOTE SENSING RESEARCH

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The general long term goal is to establish the role that visible and near infrared remote sensing can play in limnology and coastal zone oceanography. Specific objectives include the identification of potential users and their requirements, the evaluation of the capabilities of the Coastal Zone Color Scanner on Nimbus-7, and the definition of the limits of the usefulness of remote sensing techniques through radiative transfer modeling.

The approach being used to accomplish these objectives is to organize a Great Lakes experiment team and to conduct extensive ship/aircraft/satellite experiments in each lake. Active participants will include Federal and State Agencies, area universities and private industries. This direct involvement with outside interests will provide insight into user needs. The data collected during the spring, summer, and fall of 1980 will be used to meet those needs and to evaluate the CZCS. The data will also be used to test and improve radiative transfer models. These models will, in turn, be used to study improvements in sensors and to predict the limits of remote sensing in meeting user needs.

Key scientific investigators will be identified at the next general meeting of the Great Lakes Experiment Team to be held March 20 and 21, 1980.

DETERMINE THE UTILITY OF SEASAT SAR FOR OCEAN  
WAVE DETECTION.

Principal Investigator: Mr. Robert C. Beal  
The Johns Hopkins University  
Applied Science Laboratory  
Johns Hopkins Road  
Laurel, MD 20810

Objective: Determine performance range over which Seasat-SAR accurately measures predominant ocean wavelength and direction and find the small gravity wavelength region for which the isotropic roughness modulation model is most valid.

Approach: Data will be collected from each of the three to five test sites and recorded simultaneously with the Seasat-A over-flights during the first six months. Then the data from each of the sensors will be converted to a useful format for sensor cross-correlations, primarily involving optical Fourier transform effort. The last phase will involve data analysis and reporting in which correlations between sensors are examined for significant implications.

Status: A final report for the first year effort has been completed: "The Seasat SAR Wind and Ocean Wave Monitoring Capabilities," A Case Study for Pass 1339M, 28 September, 1978, JHU/APL SIR 79U-019, August 1979 by Robert C. Beal. This report was accepted as fulfillment of Contr.-No. MO-A01-78-00-4330. Additional papers have been published in Science and presented at several technical meetings.

A proposal for continuation of this research has been submitted.

This work is jointly funded by NOAA and NASA.

## AN OCEAN MESOSCALE EDDY INVESTIGATION UTILIZING SEASAT-A SMMR DATA

Principal Investigator: Dr. Robert L. Bernstein  
Scripps Institution of Oceanography,  
A-030  
University of California  
La Jolla, CA 92093

Objective: Production of sea surface temperature maps with spatial resolution as fine as possible from the Seasat SMMR data. The time sequence of maps will be used to study the evolution of eddying and meandering currents in the Northwest Pacific Ocean.

Approach: Sea surface temperature data obtained by the Seasat-A SMMR will be assembled for the Western North Pacific, and mapped in five-day blocks. The maps will be examined for internal consistency and compared with conventional XBT data obtained by ships-of-opportunity, to establish a confidence level.

Status: I have participated in three SMMR evaluation workshops sponsored by the Seasat project in January, May, and September 1979. During this span of time the algorithms for extracting sea surface temperature have been improved considerably to the point where the data should be of useful accuracy for my purpose.

I cannot actually begin the work outlined in my proposal until at least several months of data is in hand for the region of interest. A larger and more serious problem is that the NIMBUS-7 SMMR data will be far more valuable for my study than the Seasat data set. This is because Seasat data will be useful but the NIMBUS-7 data far more so. However, the general availability of NIMBUS-7 SMMR data appears to be much further removed into the future than the Seasat data.

I am continuing to work closely with Njoku and others at JPL. We have developed a plan for processing a sufficient amount of SMMR data to begin the proposed study. If approved by the Seasat project this processing will commence in mid-January 1980.

This work is jointly sponsored by NOAA and NASA.

DETERMINATION OF TIME VARIABILITY IN THE TROPICAL PACIFIC  
CURRENT SYSTEMS

Principal Investigator: Dr. Robert L. Bernstein, A-030  
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My long-term research interests center on improving our ability to describe and understand the structure and dynamics of ocean current systems, with a focus on the use of space-based remote sensing methods. The objective of this particular investigation is to explore the capabilities and limitations of satellite altimetry in pursuit of that interest.

The approach is first to concentrate on SEASAT and GEOS-3 altimeter data sets which are spatially and temporally coincident with good quality oceanographic measurements, to quantitatively verify the altimeters' current measuring capabilities. For SEASAT, a set of air-expendable bathythermograph data was collected during September and October 1978 in the western North Pacific, using U.S. Navy P-3 aircraft. For GEOS-3, arrangements were made for the collection of its altimeter data to coincide with a NORPAX oceanographic experiment in November 1977 to March 1978, between Hawaii and Tahiti. These activities involve close cooperation with George Born and Mike Park at JPL.

The present status is that all pertinent data are in hand and being analyzed. The results for SEASAT are highly encouraging, with agreement in observed time-variability to  $\sim$ 10cm between satellite and aircraft data.

SCRIPPS INSTITUTION OF OCEANOGRAPHY  
SATELLITE REMOTE SENSING FACILITY

Principal Investigator: Dr. Robert L. Bernstein, A-030  
Scripps Institution of Oceanography  
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My long-term research interests have focused on bringing available space-based remote sensing data to bear on a range of oceanographic interests. It is recognized that these data are often difficult to obtain and process. The objective of this particular investigation, therefore, has been to establish a facility which provides marine scientists with the means to readily access data from the NIMBUS-7 and TIROS-N generation satellites, plus the ability to interactively process and extract useful information from their sensors. These include the Coastal Zone Color Scanner and Scanning Multi-frequency Microwave Radiometer on NIMBUS-7, the Advanced Very High Resolution Radiometer, High Resolution Infrared Sounder and ARGOS Data Collection System on the TIROS-N series.

The approach in establishing the facility involved first seeking a base of scientific support locally at Scripps in 1976, followed with design studies in 1977 and 1978. Those studies relied very heavily on several people at JPL, including Nick Renzetti, Steve Kent, Bob Evans, Joel Seidman and Ron Casperson. Funding to build the facility was provided by NASA and ONR in mid-1978.

The present status is as follows: the facility was delivered to Scripps in mid-1979, and declared operational in October 1979. It consists basically of a 5 m diameter S-band tracking antenna, and a HP3000 mini-computer-based image processing system. A small staff of engineers and programmers work to enhance system capabilities and assist oceanographers in learning how to use the facility. A user committee has been established to provide guidance. It is chaired by Prof. Chris Mooers, chairman of the Naval Postgraduate School's Department of Oceanography. Several major oceanographic field experiments have been successfully supported since the facility became operational.

In addition to support from NASA and ONR, NSF has provided funding to cover much of the operating costs for the first two years of facility operation. The Navy Ocean System Center in San Diego has provided support also through the involvement of Norm Ortwein. Continued involvement by JPL personnel under Renzetti provide engineering support to the facility through NASA funding.

EPA/JPL LAKE CLASSIFICATION RESEARCH,  
DEMONSTRATION AND TRANSFER PROJECT

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The project objective is to demonstrate and transfer to the U.S. Environmental Protection Agency (EPA), the technology and capability to utilize remote sensing data to augment and enhance the EPA water quality monitoring program. Specifically, the project will: (a) develop and further refine techniques and procedures for using Landsat and aircraft multispectral scanner data to characterize eutrophication in inland fresh-water lakes, (b) develop methods for utilizing existing water quality environmental data bases in conjunction with remote sensing to extend the useful life time of the data base as well as to augment its capability, (c) develop procedures for incorporating data about land use practices and the diurnal and seasonal variations in water quality and, (d) transfer this technology to the EPA for operational use so as to assist in the development, maintainence and updating of the water quality data base relative to lake classification and trophic indices.

Demonstration projects have been conducted for seven specific areas. Using satellite and aircraft multispectral data and water truth samples, computer programs, procedures and methodologies have been developed, implemented, and tested to produce relative trophic rankings of lakes and mappings of the various trophic classifications within lakes. Inferences concerning amounts and magnitudes of specific trophic indicators such as chlorophyl a and secchi disk transparencies have been drawn using correlation techniques and principle component analysis methods with the various data types.

During the past year the task objectives have been shifted towards the development of documentation of the specific results of the demonstration results. The report will also include a discussion of the software system developed from this project. The issuance of this report will conclude the project.

## THE RESOLUTION CAPABILITY OF THE SEASAT RADAR ALTIMETER

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Objective: To determine the capability of the SEASAT radar altimeter to resolve short wavelength features in the ocean geoid and in the gravity disturbance vector.

Approach: The determination of the resolution capability of the SEASAT radar altimeter for geoidal and gravity variations is based on an analysis of the altimeter data collected along nearly repeating satellite subtracks. These subtracks often repeat to within a spacing of less than 2 or 3 km, a small distance compared with the significant correlation distances of geoidal and gravity disturbance quantities. Accordingly, an analysis of the repeatable portion of the altimeter data collected along these subtracks affords a quantitative measure of the resolution capability.

Results: To date, more than twenty-five pairs of the "repeat tracks" have been analyzed in various oceanic regions. The results show an effective resolution limit for geoidal variations in wavelengths of approximately 30 km. This means that on the average, geoidal features with significant wavelengths shorter than 30 km cannot be resolved with the altimeter data, but that the altimeter has a significant capability for resolving geoidal features whose spectral content is concentrated in wavelengths longer than this limit. Results of this type are significant from the point of view of mission planning (i.e., defining satellite subtrack grid structures) and of determining the appropriate resolution for data products (i.e., maps of the geoid and gravity anomalies).

To explore the potential for detecting and locating ocean geoidal and bathymetric features whose physical dimensions may be smaller than the average resolution capability, TASC has initiated an effort to design a special class of matched filters for detecting seamounts. Results to date have shown the feasibility of detecting seamounts whose physical size is as small as 10 km at a depth of 2 km with the SEASAT radar altimeter data.

This work is jointly supported by NOAA and NASA.

## REMOTE FLUORESCENCE OF PHYTOPLANKTON DENSITY AND DIVERSITY

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The long-term objective of this effort is to develop the capability to remotely measure the density and diversity of marine phytoplankton based on the fluorescence of their chlorophyll a molecules. A multi-wavelength excitation approach is being used which takes advantage of the characteristic fluorescence excitation spectra of the four major algae color groups. Laboratory studies have shown that the fluorescence energy produced by a particular organism is linearly proportional to the concentration of chlorophyll a in that organism and that the relative response to different excitation energies can be used to characterize the color group to which the organism belongs.

Specific objectives of this investigation are (1) the completion of laboratory studies that are the basis for the fluorosensor concept verification, and (2) documentation of both laboratory and field tests of the system. Field tests include the Narragansett Bay experiment in March 1978, and tests near the mouth of the Chesapeake Bay which included both continental shelf waters, low in chlorophyll, and turbid Chesapeake Bay waters, with chlorophyll levels as high as 20  $\mu\text{g/l}$ . The Narragansett Bay experiment demonstrated the capability of the system to provide quantified total chlorophyll a and to discriminate accurately between golden-brown and green algae.

The various flight experiments have suggested certain approaches to the fluorosensor algorithm. Specifically, there is a need to separate parameters that are environment-dependent, (e.g., fluorescence efficiencies) from parameters that are independent of environmental influences. These parameters have been identified and laboratory data are being used to verify the choice. Environment-independent relationships will be taken as *a priori* information, before a flight mission, and environment-dependent parameters will be estimated using sea truth. This process will greatly reduce the amount of sea truth required and will provide the capability for valuable real-time information on relative chlorophyll levels and relative population diversity.

## USE OF RADAR ALTIMETER CROSS SECTION MEASUREMENTS TO INFER OCEAN SURFACE WIND SPEEDS AND ICE CHARACTERISTICS

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Objective: Study the use of Seasat radar altimeter average return power measurements to estimate surface wind speed and ice surface characteristics such as homogeneity and roughness.

Approach: Compare Seasat altimeter-derived wind speeds to wind speeds observed at NOAA data buoys, and test a relationship derived from GEOS-3 satellite data which relates wind speed to scattering cross-section. Determine the precision of this technique over low (0-4m/s), moderate (4-10m/s), and high (>10m/s) wind speed ranges. Estimate the degree of spatial homogeneity in local wind fields.

Status: Efforts to date have primarily been directed toward calibrating the Seasat altimeter's measurement of  $\sigma^0(0^\circ)$  against similar measurements obtained from the GEOS-3 altimeter and the Seasat SASS nadir cells. The comparisons show the Seasat altimeter measurement to be high by 1.6 dB. In addition comparisons have been made between the Seasat  $\sigma^0(0^\circ)$ -inferred wind speeds (using the -1.6 dB correction and the GEOS-3 algorithm) and buoy measurements for over eighty near direct buoy overflights. For winds in the range of 1 to 12 m/s, the mean difference was -0.24 m/s and the standard deviation of the difference was 1.57 m/s.

Efforts will concentrate on obtaining estimates of how well the altimeter can measure high surface winds, i.e. >10 m/s. Efforts will also be directed toward obtaining more GEOS-Seasat ground track intersections to examine the validity of the 1.6 dB difference in  $\sigma^0(0^\circ)$  measurements over a larger dynamic range. Initial examinations of waveform data over ice will be started in an attempt to understand the character and meaning of the scattering data.

This work is supported jointly by NOAA and NASA.

AIR-SEA INTERACTION STUDIES FOR SATELLITE MEASUREMENTS  
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Long term goals are aimed at improvement of large-scale weather analysis and forecasting. Efforts are directed at upgrading the air-sea interaction algorithm for use in the general circulation models (GCM). It is felt that a good model of the planetary boundary layer (PBL) dynamics (and therefore the heat and momentum fluxes) will greatly improve GCM capabilities. Work has evolved from fundamental investigation of stability and stratification effects in the basic fluid dynamics of the PBL to the application of these results to a practical, comprehensive large-scale PBL model.

For the specific application to the proof-of-concept for SEASAT microwave wind measurement capabilities, the PBL model was adapted for the marine PBL and used to provide comparison wind fields compatible to the SASS and SMMR predicted wind fields. The reliability of satellite sea surface temperature field predictions must be established concurrently, for their own value and their importance to the wind models. Current objectives include continued development and comparison of field and satellite data to establish the capability, limits and specific algorithm for interaction between satellite data and GCM's.

The wind model is designed to empirically represent important details of PBL flow in a simple algorithm which is easily added to GCM's. It includes Ekman layer instabilities/secondary flow and single parameter similarity theory of R.A. Brown, surface layer stratification of J.A. Businger, surface roughness variation and interfacial layer effects from T. Liu and accounts for humidity and thermal wind effects. K. Katsaros' basic work on sea temperature verification and accuracy is also important to wind models and measurement. The above mentioned Univ. of Washington personnel have all worked on large-scale experiments designed to provide surface truth wind and temperature data. Current work is aimed at developing the measurements from JASIN and MARSEN to compare with satellite data. Simultaneously, the best method of incorporating satellite data into simple air-sea PBL models and thereby into forecast models, and the significance is being investigated. Some of the work is done in close cooperation with P. Woiceshyn at JPL to keep up with satellite algorithms.

The Gulf of Alaska Experiment (GOASEX) comparisons with SEASAT data established definite correlations between observed winds and temperatures and satellite data. However, more controlled data comparisons are needed to establish the satellite instrument accuracies, field recognition capability (e.g. front locating) and ability to supply GCM modeling needs. The high quality JASIN and MARSEN data should satisfy this. In addition to NASA support, we have NSF (RAB) and ONR and NOAA (KK) funding, in related work.

## RAPID SAMPLING VERTICAL PROFILER

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Our long term interest with which this project deals lies in the exploration of the variability of the upper ocean and in the elucidation of the processes which govern the distribution of heat, salt and momentum in near-surface waters. The objective of this particular project is to develop an instrument system capable of producing profiles of oceanic variables, initially heat and salt, when deployed from a moving ship.

Our approach to this task involves a small probe connected to a thin line which provides both data link and retrieval mechanism. The probe falls at several meters per second, trailing the line behind it, and then is winched back to the ship. A high-speed digital data acquisition system on board the ship records during descent. The probe is then retrieved and relaunched. A pressure signal is recorded as well as temperature and electrical conductivity, so that these variables can be plotted as functions of depth. Continuation of this process will then produce a map in two dimensions of the variations present.

As of the date of writing this project has been underway for ten months and present funding continues for another eleven months. A prototype system recording only temperature and depth was tested from the R/V OCEANOGRAPHER in the North Pacific in January 1980 with considerable success: a sequence of 25 profiles was obtained with the ship moving at eight knots and a shorter sequence at eleven knots. Repetition time was five minutes and the depth reached was approximately 120 meters. Work now centers on adding conductivity, increasing reliability and ease of operation, and constructing a suitable data acquisition system.

## OCEAN CIRCULATION STUDIES USING SEASAT ALTIMETER PROFILES

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### Long Term Interests

The Seasat altimeter data set is unique in its accuracy and spatial coverage. We intend to derive as much ocean circulation information as possible from the data, expanding our investigation of the western North Atlantic to include other areas. The capabilities of altimetry for subsequent oceanographic missions will be explored.

### Specific Investigation Objectives

The purpose of ongoing studies is to develop techniques for extracting details of circulation in the western North Atlantic from Seasat altimeter profiles. In addition to the detection of features such as the Gulf Stream and rings, the goal is to accurately derive quantitative parameters such as surface current velocities and, using models, to interpret sea surface heights in terms of ocean dynamics.

### Approach

Detection of mesoscale ocean currents with an altimeter requires removal of the gravitational component from the altimeter signal. Seasat profiles are being differenced with a detailed gravimetric geoid and other geoid models to produce residual sea height profiles. These are compared with surface truth charts, compiled especially for this period from all available oceanographic data, to determine the most reliable technique.

### Status

A number of passes of data have been examined using a detailed gravimetric geoid as a reference. Results show that mesoscale features in the Gulf Stream system can be accurately detected by this technique, and quantitative analysis seems feasible. Comparison of Gulf Stream profiles with a numerical model by T. Kao at Catholic University shows remarkable correspondence. Altimetric geoid models will be tested next.

We are working with Code 933 at Goddard and Science Applications in McClean, VA to develop interactive methods of working with the altimeter data, such as the capabilities available with a Tektronix scope. This would provide instantaneous access to any profile in the data set, with corresponding speed of analysis. The system we envision will have clear applications for real time use with future satellite altimeters.

## OIL SPILLS AND OCEAN WASTE MONITORING

Principal Investigator: W. F. Croswell, NASA Langley Research Center, Mail Stop 490, Hampton, VA 23665, 804 827-3631, FTS (928-3631)

Long Term Interests: To provide a quantitative scientific basis for the detection and monitoring of oil spills.

Specific objectives: (a) Conduct field experiments of accidental and controlled spills of oil on the sea using a variety of microwave and optical sensors in order to obtain a quantitative understanding of how images of pollutants are formed. (b) Analyze the experimental data to obtain overlayed imagery of near identical scenes in order to define possible relationships between physical oil temperature and thickness and image intensity.

Approach: A comprehensive series of field experiments were conducted in 1978 and 1979, in cooperation with the American Petroleum Institute, EPA, NOAA, USCG, the Canadian Centre of Remote Sensing, and NASA Wallops. Nearly simultaneous aircraft measurements were obtained with laser fluorosensors, L and X-Band SAR, X-Band SLAR, L-Band, 22 and 31 GHz radiometers, IR and MSS scanners,  $\mu$ v scanner, and color and IR photography. All of these sensors have previously detected oil in the laboratory or field. Sea truth samples were obtained from surface vessels as a function of depth along sea and atmospheric conditions. Key scientific investigators are R. A O'Neill, CCRS, J. Johnson, JBF Scientific, F. E. Hoge, H. Maurer, NASA Wallops, J. Johnson, H-J. C. Blume, NASA Langley, and R. Rawson, ERIM.

Status: All data has been initially reviewed and prime data sets have been identified. Laser fluorosensor analysis including oil type and oil thickness using Raman Line suppression is completed with papers in press. All microwave radiometer 22 and 31 GHz data is reduced. From this analysis, surface truth and laser fluorosensor results a joint paper on oil volume and type is under preparation. An initial analysis of the MSS, IR, and  $\mu$ v scanner data is complete; quantitative analysis of these results is planned. A lengthy effort to determine how to properly digitize the SAR data is completed. This is particularly important because in addition to ocean scenes, land scenes with calibrated corner reflectors were obtained each experiment. All SAR data will be digitized this spring. This research is expected to be completed in 1 year.

## SAR ICE MOTION ALGORITHM DEVELOPMENT

Principal Investigator: Dr. Charles Elachi  
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Objective: The long-term objective is to assess and develop the capability of spaceborne imaging radars to map polar ice motion on a large scale. The specific objective of this research is to develop the algorithms necessary to measure ice motion using SEASAT SAR images. The following aspects are being addressed: (i) assess the accuracy with which the ice motion can be measured using the SEASAT SAR, and (ii) determine the parameters which are the most critical in achieving a certain accuracy.

Approach: The technical approach is: 1) Use SEASAT images of well-mapped land features to determine the accuracy of the algorithm results. 2) Test the algorithm on two successive SEASAT paths over the same ice-covered region in the Arctic Sea. Use near-shore region such that fixed land points can be used as a reference to derive the ice motion. This research is conducted jointly with Professor F. Leberl from the Technical University of Graz, Austria, who is a well-known expert in radargrammetry, and with Drs. W. Campbell and C. Lin from USGS in Tacoma, WA.

Progress Status: The results of this study for FY79 and the first quarter of FY80 are: 1) The region south of the Salton Sea was selected to test the measurement accuracy. A total of 52 points were identified on the radar images and the maps. Cartographic digitizing equipment with accuracies of about  $\pm 0.05$ mm was used to measure the image coordinates of these points on the SEASAT image. Image scale was 1:250,000. Using a bilinear correction function for the radar image, the radargrammetric positioning of the points on the ground was better than  $\pm 200$ m in flat terrain. 2) Five SEASAT images of the near-coast region just west of Banks Island were used to measure the ice motion. The images were obtained over a period of 24 days, from mid-September to early October 1978. A number of ice flows were traced and their motion measured. Motions of up to 110km over the 24-day period were observed. It was found that it is best to identify and track point-like features. During the rest of FY80, the work will be completed and an open literature paper submitted for publication.

ANALYSIS OF SEASAT-A SAR DATA FOR THE  
DETECTION OF OIL ON THE OCEAN SURFACE

Principal Investigator: Dr. John E. Estes  
Geography Remote Sensing Unit  
University of California  
Santa Barbara, CA 93106

Objectives The aim of this research is a verification of space-borne SAR's ability to detect oil accumulations in a marine environment. The response of such active microwave imaging devices to these pollution targets is well documented for low altitude platforms. The question addressed here, however, is whether the small scale reductions in ocean surface roughness effected by oil slicks are sufficient to noticeably reduce the radar backscatter cross-section coefficient at orbital altitude and resolution.

Status The premature failure of Seasat-A before the scheduled completion of surface verification tests was cause for extensive contractual revisions.

It was hypothesized that if some means of predicting oil slick conditions in the study area during the Seasat overpass times could be developed, then the satellite data itself might be evaluated in terms of target detection on something of an authoritative basis. With this in mind work was begun on a oil slick trajectory model (OSTM).

To this time several experimental runs of the OSTM have been completed which incorporate variable influences of wind, current, and tide. A finalized algorithm has yet to be selected, although test runs are increasing in stability indicating that future alterations will be minor. The model is highly dependent on input data for resolution, and furthermore is noisy in the amount of impact it assigns to the tidal factor.

As points of origin are known, however, and since the volumes of oil released are small, these sources of inaccuracy are deemed acceptable within the framework of the model's application.

In its present form which does not include the smoothed current data OSTM predictions are very good for periods of strong incoming tides. Accuracies of  $\pm 10$  degrees are observed. For slack and ebbing tidal phases results are more nebulous. All three of the Seasat datasets (Rev's; 308; 552; 617) available for the Santa Barbara Channel study area occurred during flow tidal phases. On two of these three, plumes of diminished radar backscatter are observed originating in areas of well documented oil seepage and projecting away from these assumed points of origin at headings in close agreement with OSTM predictions.

This work is supported jointly by NOAA and NASA.

STUDY OF SURFACE WINDS AND SEA SURFACE TEMPERATURES OVER  
THE INDIAN OCEAN USING SEASAT-A DATA

Principal Investigator: Dr. Mariano A. Estoque  
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Science  
University of Miami  
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Objectives:

1. Validation, including calibration, of surface winds and sea surface temperatures obtained by Seasat-A against independent observational data.
2. Detailed study of the synoptic features of the surface wind field associated with the monsoons.
3. Corresponding study of sea surface temperatures and study of the interrelationships between the surface wind and the sea surface temperatures.

Approach: Construct detailed distributions of the surface wind and the sea surface temperatures. A streamline-isotach analysis will be done to produce detailed maps of surface wind distribution; corresponding maps will be drawn for sea surface isotherms to exploit the horizontal (100 km) and time (36 hr) resolution of the Seasat-A data. Maps based on these data will, in turn, be validated and corrected against independent observations. Finally, the corrections will be incorporated in producing the final surface wind and sea surface temperature distributions.

Status: Work done during the period consisted primarily of obtaining data. We have now acquired surface observations from ships and island stations for the Indian Ocean area for the time Seasat-A was in operation. We have also obtained magnetic tapes containing the Seasat Interim Geophysical Data Records produced by the Jet Propulsion Laboratory.

Work in the immediate future will involve plotting and analyzing conventional surface data (wind and temperature) for use in the validation of the Seasat observations. We will also read the Seasat data tapes and begin the validation studies.

This work is supported jointly by NOAA and NASA.

## SEASAT SAR TEST OF VIRGINIAN SEA WAVE CLIMATE MODEL

Principal Investigator: Dr. Victor Goldsmith  
Virginia Institute of Marine Science  
Gloucester Point, VA 23062

Objective: Test SAR image data against the wave ray predictions of the existing Virginian Sea Wave Climate Model (VSWCM) applied to the continental shelf between Cape Hatteras and Long Island. Results will be verification of usefulness of SAR for wave-train analysis and verification of the VSWCM from slope water to the shoreline.

### Approach:

1. To compare maps of wave-trains from Seasat SAR data with wave ray predictions of the VSWCM in this region;
2. To examine, in areas where Seasat SAR data and VSWCM predictions are in disagreement, what changes in input data can correct such disagreements; and
3. To evaluate in preliminary fashion whether future Seasat SAR data obtained in deep water areas can be used in conjunction with wave refraction models to predict wave climate at the shoreline.

Status: Wave-train data so far obtained from Seasat SAR data reduction were studied with image interpretation and spatial Fourier analysis. Wave-train data for the Virginian Sea region are available and one or two SAR passes will be selected for analysis. However, maximum benefit will obtain from analysis which also includes other, unstudied, coastal regions because others contain as clear or clearer wave patterns. The Virginian Sea Wave Climate Model (VSWCM) has been successfully applied outside the Virginian Sea in several instances, thus, use of the VSWCM and Seasat SAR data for other regions is only a matter of collecting the needed bathymetric data for input to the model. Mr. Reginald Exton of NASA Langley has agreed to help produce spatial Fourier spectra using NASA Langley laser facilities. The immediate plan is to complete review of all SAR imagery, select four passes for study, obtain copies of the respective imagery, and initiate graphical analysis and spatial Fourier analysis.

This work is supported jointly by NOAA and NASA.

## OCEANIC EDDY HEAT AND MOMENTUM FLUXES AT THE CONTINENTAL MARGIN

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Idealized dynamical studies of the coupling which exists between the large-scale oceanic general circulation and motions along the continental shelf and slope are being carried out. The immediate goal is to understand the interaction between coastal and large-scale ocean circulations; ultimately, we hope to parameterize (1) the boundary constraints imposed on large-scale ocean current systems by the presence of the continental shelf (and vice versa) and (2) the exchange processes taking place across their common boundary. A detailed knowledge of the operative continental shelf/deep ocean coupling mechanisms is of considerable practical importance for a variety of human concerns including climate, waste disposal, and ocean resource development problems.

Our specific approach is to construct and to study a simple numerical model of the combined continental shelf/deep ocean system, paying particular attention to heat and momentum exchange across the continental shelf break. Prompted by recent theoretical and observational evidence, three forcing and/or coupling mechanisms will be investigated: imposed atmospheric wind stress and surface pressure distributions, longshore sea level variations, and propagating energetic mesoscale motions incident on the continental slope from the exterior oceanic environment. Now under development, the model incorporates (in idealized form) the effects of finite-amplitude topography, coastal geometry, long-period sea level fluctuations, stratification and rotation.

During the present grant period, objectives include: (1) model implementation; (2) model testing, including evaluation of the boundary condition scheme and model behavior for several simple mean flow and shelf wave problems; and (3) initial scientific study of the heat and momentum transfers accompanying a single, shoreward-propagating isolated eddy disturbance. Apart from some initial program development, to be carried out at the Woods Hole Oceanographic Institution, computations will be conducted primarily at the Goddard Laboratory for Atmospheric Sciences.

SEASAT SCATTEROMETER WIND DATA ASSIMILATION AND FORECASTING  
IMPACT STUDIES

Principal Investigators: Dr. M. Halem and Dr. E. Kalnay-Rivas,  
Modeling and Simulation Facility,  
NASA/GSFC, Code 911, Greenbelt, MD 20771  
(301) 344-7482

The main purpose of this investigation is to determine the improvement on numerical weather prediction, that can result from SEASAT - A Scatterometer data. We plan to complete the processing, analyses and a preliminary test of three days of SEASAT and conventional data for some period in September 1978.

The processing will involve two techniques for the removal of the alias in the SASS winds. First, an automatic procedure in which the SASS wind is chosen with direction closest to the GLAS model analysis of the surface wind, and second, a subjective choice of the wind vector in best agreement with other available data bases on the use of a Man-Computer Interactive Data Access System (McIDAS).

The SASS winds will then be objectively analyzed and assimilated along with conventional data and satellite cloud-track winds into the GLAS model for three continuous days. The resultant model analyses will then be used as the initial condition for a numerical weather forecast. The experiment will also require a control forecast from initial conditions obtained without SASS winds.

An important application expected from this experiment will be an estimate of the surface wind stress over the oceans.

Thus far, the following has been accomplished:

- 1.) Acquisition of the SASS wind data for September 1978,
- 2.) Acquisition and processing of all conventional data including surface ship and upper air data for September 1978,
- 3.) Coding completed and testing begun on the alias removal procedure within the objective analysis scheme,
- 4.) Software is under development for staging SASS wind data on McIDAS to perform alias removal subjectively,
- 5.) Completed rewriting a version of the GLAS model with high resolution near the surface,
- 6.) A Richardson number type planetary boundary layer is nearly checked out.

Key Personnel: NASA staff conducting these studies are Drs. M. Halem, E. Kalnay-Rives, W. Baker, and M. Helfand for implementation of the PBL parameterization and SASS data assimilation, Dr. R. Atlas who is developing and performing the McIDAS analysis. Prof. M. Cane and an MIT graduate student who will participate in the experiments and analysis of the results.

## OCEAN MODELING AND PREDICTION

Principal Investigator: Dr. M. Hale and Dr. J. Shukla, Modeling and Simulation Facility, Code 911, GSFC, (301) 344-7482

The climate group of the Modeling and Simulation Facility is studying the extended prediction of atmospheric means for months or seasons. As such, the longer term evolution of the lower boundary conditions is of interest, specifically the behavior of sea surface temperature (SST). The ocean modeling and prediction effort centers around this question, supplemented by work on ocean heat transport mechanics and upper ocean dynamics.

Specifically, we are examining the formation and maintenance of SST anomalies by: (a) anomalous time-history of surface fluxes and (b) dynamically induced perturbations within the ocean. This effort involves:

- Data studies of the North Atlantic and North Pacific Oceans. Statistical interpretation of SST interaction with local heat fluxes and wind mixing are underway. Interpretation of the correlations and spectra is being completed, furnishing information about the expected oceanic response to local anomalies in forcing. (J. Calman, NRC/RRA with Code 911)
- Global studies of the response of local thermodynamic models to climatological- and GCM-produced surface fluxes. This is an extension of the sensitivity studies on one-dimensional mixed-layer behavior done by I. Fung and M. Cane. The effects of temporal averaging of the flux fields and Ekman and geostrophic currents are being studied through comparative experiments. (P. Schopf, Code 913, and J. Calman)
- Development of a three-dimensional dynamic-thermodynamic model of the upper ocean. This model is being used to conduct studies of equatorial dynamics, Somali current response of the Southwest monsoon, and mid-latitude eddy processes. Coupling with the atmospheric GCM is envisioned, as are studies of ocean heat transport. Air-sea interaction has been seen both as a dynamic influence on SST, and as a surface heat flux influence on upper ocean dynamics. (J. Shukla, Code 911, M. Cane, MIT, and P. Schopf)
- Analysis of surface wind data. Ocean merchant ship wind reports (TDFH marine surface deck) are being analyzed in support of the above work. This analysis differs from other available compilations of wind data by its high spatial resolution, the inclusion of error analysis and the calculation of the turbulent energy flux into the ocean ( $\bar{U}^3$ ). (D. Harrison, MIT)

The ocean modeling and prediction effort is being done in close collaboration with Profs. M. Cane and D. Harrison of MIT.

## OCEAN MODELING AND DATA ANALYSIS STUDIES

D.E. Harrison  
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Long term interests center around understanding the physical processes that are important in the low frequency ocean general circulation, in learning how to model the ocean on these scales and in using ocean models to investigate the role(s) of the ocean in the earth climate system. This requires knowledge of the air-sea interaction processes which produce the surface heat, salt, mass and momentum fluxes that drive the ocean and also how to parameterize the effects of ocean "turbulence" on the flow scales of interest.

Specific investigation objectives are of two types. The first involves the development and use of numerical ocean models with various degrees of physical sophistication, in order to study the effects of different ocean processes in sufficiently idealized circumstances to make their effects understandable. The second involves ocean data analysis projects directed at determining how well the ocean wind stress and sea surface temperature fields are known on different space and time scales from conventional observations. These fields are needed for various modeling studies and also establish the standards that satellite observing systems should meet for maximum utility.

This work is carried out at the Goddard Laboratory for Atmospheric Sciences, Modeling and Simulation Facility, with support personnel and computing resources made available by GLAS. Close contact with other GLAS scientists is maintained and the investigator serves on the MSF staff as a Faculty Research Associate.

These activities are beginning Fiscal 1980. Other support for the investigator is received from NSF, ONR and NOAA.

## NUMERICAL MODELING OF SEA ICE DYNAMICS AND ICE THICKNESS CHARACTERISTICS

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This research effort is largely motivated by a long term interest in air/sea interaction in the presence of an ice cover. The main objective of this specific program is the development and verification of numerical models for simulating the large scale dynamics and thermodynamics of sea ice. Particular emphasis in this work has been placed on developing a sea ice circulation model suitable for simulating the dynamic/thermodynamic behavior of sea ice over a seasonal cycle.

The approach in this work is to combine parameterizations of various physical processes to form a model. The resulting model is then examined numerically to determine its agreement with observations and to identify the role of different processes in the model results. In numerical investigations to date, emphasis has been placed on seasonal equilibrium simulations of the Arctic ice cover. Much of the computational portion of this research has been performed at the Geophysical Fluid Dynamics Laboratory, Princeton.

During the past year, a number of refinements have been added to an existing two level dynamic/thermodynamic sea ice model (Hibler, 1979). Most notably (a) a more complete thermodynamic code together with a simple oceanic mixed layer have been added; and (b) the thickness and strength equations have been generalized to include a variable thickness ice cover consisting of an arbitrary number of irregularly spaced thickness levels. In this variable thickness model, open water creation due to shear and redistribution of ice due to deformation are included. The numerical scheme is formulated in a fixed Eulerian grid with advection terms explicitly included.

To examine the behavior of this more general model (and to determine to what extent a less complex model may be used for certain applications) a hierarchy of seasonal experiments for the Arctic Basin has been initiated. The hierarchy of experiments includes a multi-level simulation (8 thickness levels), a two level model, and a thermodynamics only simulation. A description of this model and an examination of initial simulation results is presently being written up for journal submission.

In addition to NASA, this work has been funded by the Office of Naval Research. Also, computer support has been provided by the Geophysical Fluid Dynamics Laboratory, Princeton.

## APPLICATIONS OF LASER TECHNOLOGY

Principal Investigator: Frank E. Hoge, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 567, FTS 928-5567.

Long Term Interests: To demonstrate that existing airborne laser technology and electronic systems can provide valuable, synoptic quantitative physical and chemical oceanographic data about the subsurface water column.

Specific Objectives, Approach and Progress: A. Chemical Oceanography.

(1) To demonstrate the accurate, calibrated integrated water column measurement of phytoplankton by observing the airborne laser induced fluorescence emission of chlorophyll a at 685 nm. This work is in conjunction with NASA/LaRC, Johns Hopkins University, and W. Chester St. College. Good correlation of water-Raman-normalized airborne chlorophyll a fluorescence emission at 685 nm has been made with chlorophyll a extractions of grab samples taken along the flight lines. (2) To demonstrate the accurate, calibrated, integrated water column measurement of dissolved organic matter (DOM) and particulate organic matter (POM) in near-shore oceanic regions by laser-induced fluorescence. Recent important research results indicate that these DOM humic polymers may be produced and recycled by phytoplankton thus entering into primary marine productivity schemes. Airborne laser induced fluorescence of naturally occurring organic matter in coastal and estuarine waters has been observed using a 337.1 nm N<sub>2</sub> laser as the excitation source. Water Raman backscatter signals having sufficient strength for calibration have also been observed. B. Physical Oceanography. (1) To demonstrate the depth resolved measurement of ocean water temperature by remote airborne laser induced Raman scatter techniques. No method currently exists to remotely measure the subsurface ocean temperature profile. Laser induced Raman backscatter spectral bandshape and isomer/dimer depolarization techniques will be utilized to extract the remote temperature profiles. This work is in conjunction with Navy (NAVAIR/NRL) and requires some subcontracting. Subsurface water temperature measurements using a boatborne lidar have been demonstrated. Water Raman backscatter signals have been observed by NASA/WFC from airborne platforms over ocean water. To date these signals have only been used to remotely measure oil film thickness and absolute dye tracer concentration.

(2) To demonstrate the remote measurement of water column diffuse attenuation coefficient by using the water Raman backscatter decay as a function of depth. Better quality airborne Raman bathymetry data complete with diffuse attenuation sea truth is needed together with better deconvolution algorithms to remove lidar system response time. (3) To demonstrate ocean front detection and measurement by means of Raman signal depression, chlorophyll a and organic material fluorescence gradients. An estuarine front has been detected by means of Raman depression and correlated with photographic truth data.

## MICROSCALE OCEAN SURFACE DYNAMICS

Principal Investigator: N. E. Huang, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 357, FTS 928-5357.

Long Term Interests: These air-sea interaction processes control the flux of momentum, energy, mass, and heat from air to water and vice versa; therefore any changes either in the air or in the water will be reflected in corresponding changes of the surface microscale structures in the form of wind waves. Consequently, the study of the microscale ocean surface dynamics will not only increase our understanding of the air-sea interaction processes, but also provide us with the foundation for proper interpretation of microwave remote sensing data.

Specific Objectives: (1) To study the detailed statistical characteristics of the ocean surface. (2) To study the spatial and temporal relationship of the wind waves, and (3) to study the evolution of the wind waves and their relationship to the turbulence intensity in the surface layer. The approach adopted here is to conduct a selected number of carefully controlled experiments first in the laboratory at wind-wave-current interaction facility at WFC and then to check these results out in the field. At the same time theoretical analysis will also be emphasized. Our aim is to understand the basic physics of the processes. Therefore the approach will be more analytical and physical rather than empirical. This study is conducted as a joint effort between NASA Wallops Flight Center and Prof. O. M. Phillips of the Johns Hopkins University and Prof. C. C. Tung of the N.C. State University.

Progress: All the studies are in progress. The major findings are: (1) From theoretical and experimental study, we found the wave skewness  $K_3$ , is related to the slope of the waves by  $K_3 = 8\pi \varsigma$ , where  $\varsigma$  is the significant slope of the waves, defined as the ratio of rms surface elevation to the length of the waves at the peak of the spectrum. Subsequent analysis also demonstrated the feasibility of calculating  $K_3$  from the altimeter return pulse shape. Coupled with the wave height measurement, we can derive the wavelength or the frequency of the dominant waves. (2) From theoretical analysis, we arrived at a result that the Phillips equilibrium range constant  $\beta$ , could be expressed in terms of the significant slope too, i.e.  $\beta = (4\pi \varsigma)^2$ . This relationship is compared with both laboratory and JONSWAP field data and the agreement is very good. (3) Theoretical analysis of the surface drift current under both wave and wind stresses showed that the current structure of the surface layer is much more complicated. In addition to the Ekman layer, a Langmuir layer is possible. The detailed structure is determined by the Ekman number. Partial support comes from Department of Interior, Bureau of Land Management.

## MICROWAVE RADAR OCEAN INVESTIGATIONS

Principal Investigator: F. C. Jackson, Code 912, NASA/GSFC  
Greenbelt, Maryland 20771, FTS-344-5380

The work under this task is guided by the end objective, which is to see developed simple (e.g., low cost, low data rate, etc.) non-imaging microwave radar systems for satellite measurements of open-ocean, wind-wave directional spectra. To this end we are pursuing a combined program of theoretical modelling, systems analysis, and aircraft data analysis.

The basic principle underlying the non-imaging radar measurement is similar to that of Bragg backscatter: Only those two-dimensional Fourier surface "contrast" waves having wave vectors  $\underline{K}$  directed along the radar line-of-sight and having magnitudes  $K = 2(w/c)\sin\theta$  will contribute to signal modulation power at the frequency  $w$ . ( $\theta$  is the angle of incidence.) The actual detection of the range-travelling "contrast" wave can be accomplished using short-pulse or two-frequency techniques.

Theoretical modelling and aircraft experiments have (for several reasons) concentrated on near-vertical specular backscatter ( $\theta = 10^\circ$  to  $15^\circ$ ). It has been shown theoretically that

- a. For a Gaussian surface the predicted radar-observed directional "contrast" spectrum bears a good fidelity to the large ocean wave directional slope spectrum.
- b. Narrowband two-frequency systems are inferior to practical short-pulsed systems in terms of measurement signal-to-noise (SNR) and contrast ratios (CR).
- c. In terms of predicted SNR and CR, satellite measurements are entirely feasible. For example, the Seasat-A altimeter can perform measurements from Shuttle altitudes with a modest-sized scanning antenna.

Experimentally, on the basis of aircraft data obtained at 30 K ft. (1.2 x 0.5 km beam spot) it has been demonstrated that indeed wave spectra can be measured with a non-imaging system (a) with high directional resolution and (b) with remarkable fidelity to the slope spectrum.

A problem area to be confronted is predicting, and correction for harmonic distortion of the slope spectrum, in cases of mixed and confused sea conditions. It is felt that non-Gaussian wave statistics may be an important source of harmonic distortion. To understand these statistics we plan to use conventional and other microwave data sets in conjunction with theoretical modelling and analysis of the extensive fall '78 Goddard aircraft data set.

## MESOSCALE OCEAN DYNAMICS - SAR SYSTEM TRANSFER FUNCTION

Atul Jain, Jet Propulsion Laboratory, Pasadena, CA 91103  
(213-354-6614, FTS 792-6614)

Long term interests: Our long term interest is to define and understand the relationship, in an unambiguous and quantitative way, between the ocean surface and the SAR image as obtained from spacecraft.

Scientific objective: The present phase of research is aimed at developing the mathematical transfer function relationship between an ocean wave on the sea surface and the Fourier transform of the image of an ocean wave.

Approach: Previous work at JPL has led to a relationship between a surface whose cross-section and profile may be described by a wave equation and its SAR image. We intend to develop a description of the ocean wave by its cross-section distribution and its surface profile and include both the horizontal and vertical components of the orbital velocity in arriving at this description. The SAR system transfer function will be obtained from this result. Theory will be compared with experimental observations as obtained from the MARSEN, SEASAT, West Coast and Marineland experiments. These observations include measurements of large scale wave parameters as obtained by the surface buoys, laser profilometers, pressure sensors and the HF and 2-frequency radars and the fine scale capillary and ultra short gravity wave structure as measured by the capillary (laser-optical) wave instrument. Work is being done in conjunction with the JPL Oceanography Team, and the Max-Planck-Institute, Federal Republic of Germany.

Progress: Theoretical relationship between ocean surface and cross-section profile and the radar image have been derived, some functional predictions verified (results in review process).

Other funding: None.

## GROUND TRUTH VERIFICATION OF SEASAT-A DATA

Principal Investigator: Mr. Jerry D. Jarrell  
Science Applications, Inc.  
2999 Monterey-Salinas Highway  
Monterey, California 93940

Objective: The objective of this research effort is to study surface stress/wind estimates obtained from Seasat data and from multi-level mean and fluctuation measurements made from ships during the Marine Boundary Layer Study - West Coast (MABLES-WC) and the Joint Air Sea Interaction (JASIN) experiment, both in 1978.

Approach: Measurements inferred from the Seasat data will be compared with the available unique ground truth data collected within the satellite footprint by research vessels. The approach anticipated is to design and coordinate analysis procedures in order to make results from both sets of sensors as compatible as possible for intercomparisons. Averaging periods for shipboard results will be established and statistics which delineate temporal and spatial variability will be specified.

Status: The experiment strategy definition has been completed. Time versus geography tracks of the ships have been determined. In cooperation with the Naval Postgraduate School, time plots of the JASIN data were made. This highlighted some minor discrepancies in the data which are now being corrected. Similar treatment for the MABLES-WC data is in progress.

The time coincident Seasat orbits have been identified. The JASIN SASS data averaged over 1° squares was received in November. A routine to read and select out data records by latitude, longitude, and time has been written. Some preliminary comparisons have been made.

The work is currently being held in abeyance pending receipt of Seasat SASS spot data for both experiment areas.

This work is jointly funded by NOAA and NASA.

## ACTIVE MICROWAVE REMOTE SENSING OF OCEAN WAVE PROPERTIES/AIRCRAFT SCATTEROMETER MEASUREMENTS

Principal Investigator: J. W. Johnson, NASA Langley Research Center, Mail Stop 490, Hampton, VA 23665, 804 827-3631, FTS (928-3631)

### A. $\Delta k$ Aircraft Scatterometer

The  $\Delta k$  (formerly Dual Frequency) Scatterometer was designed to measure the spectrum of the modulation of the ocean surface capillary waves by the larger gravity wave system through coherent detection of two rf signals separated in frequency by  $\Delta f$ . The value of  $\Delta k = 2\pi\Delta f/c$  is selected to match components of the gravity wave spectrum through the Bragg condition,  $k_w = 2\Delta k \sin \theta$ . The directional gravity wave spectrum may then be inferred through application of the appropriate transfer function. Measurements of the modulation spectrum and surface currents have been conducted from stationary platforms; however, data gathered during project MARSEN in 1979, with the LaRC aircraft  $\Delta k$  system represent the first successful measurements of this type from a moving platform. Aircraft measurements give added experimental realism and flexibility and are required as the next step in exploring the measurement of ocean wave spectrum and ocean currents from space. Further analysis of MARSEN data and additional flights are planned.

Principal Investigator: D. E. Weissman, Hofstra University, Dept. of Engineering and Computer Science, Hempstead, NY 11550, (516) 560-3377, 269-5260

### B. Wave Modulation Doppler Spectrometer

The Wave Modulation Doppler Spectrometer senses the dominant wavelength component of the ocean's gravity wave system by operating at a single frequency and using an incoherent envelope detector at the receiver. This technique is based on the concept that the difference in Doppler frequency at the receiver between any two adjacent patches of scatterers stays approximately constant as they move through the antenna footprint. Successful wavetank measurements along with the theoretical development were published by Weissman and Johnson in the November 1979, issue of the IEEE Trans. Antennas Propagat. Preliminary analysis of 1979, aircraft data revealed limited success. Additional data were obtained with a different radar configuration during the MARSEN Experiment. Analysis of these data are planned for late FY 80.

## ACTIVE MICROWAVE REMOTE SENSING OF OCEAN WAVE PROPERTIES-TOWER SCATTEROMETER MEASUREMENTS

Principal Investigators: W. L. Jones, NASA Langley Research Center, Mail Stop 490, Hampton, VA 23665, 804 827-3631, FTS (928-3631), W. J. Plant and W. C. Keller, Naval Research Laboratory, Code 8344, Washington, DC 20375, 202 767-2098

The objective of this investigation is to understand the modulation of radar backscatter by gravity ocean waves and to develop analysis techniques for inferring ocean wave spectra from radar measurements. The approach taken has been to conduct field experiments using Doppler scatterometers to measure the radar backscatter amplitude and Doppler spectra along with simultaneous measurements of the gravity portion of the ocean wave spectrum. The cross correlation of these measurements has defined a radar/ocean wave modulation transfer function.

For approximately 3 years, measurements of this transfer function have been performed at 20 cm (L-band) and 3 cm (X-band) radar wavelengths. The most recent measurements were obtained on the Nordsee Tower in the North Sea during the MARSEN Experiment (September-October 1979). This experiment extended the previous data set to include measurements on deep-water waves under a variety of wind speeds.

During FY 80, the radar instrumentation has been extended to include a 8.6 mm (Ka-band) wavelength Doppler scatterometer. The plan is to conduct additional field measurements off the Outer Banks of North Carolina during the upcoming DUCKEX-II Experiment (Fall 1980).

VALIDATION AND APPLICATION OF THE SEASAT-A SMMR SEA SURFACE  
TEMPERATURE DURING THE JASIN EXPERIMENT - 1978

Principal Investigator: Dr. Kristina B. Katsaros  
Department of Atmospheric Sciences  
University of Washington  
Seattle, WA

Objective: To establish the accuracy of the sea surface temperature produced with the existing algorithms from the Scanning Multifrequency Microwave Radiometer (SMMR) sea surface temperature and near surface temperature measurements obtained in the geographical area of the Joint Air-Sea Interaction (JASIN) experiment.

Approach: Comparison of sea surface temperature obtained from Seasat-A SMMR and by the JASIN experiment teams will be analyzed independently for overlapping times. Arrays of areal averages applicable at predetermined grid points with 10 km spacing will then be calculated for both sets and the deviation calculated for each grid point. Statistical evaluation of the deviations can then be made and correlations with several other variables can be found.

Status: Five detailed surface temperature maps from aircraft data taken in the second phase of JASIN have been produced. Additional ship and aircraft data are being merged into these maps. This investigation relies on other groups to process both the surface data and the satellite data. Processing in both areas is considerably behind schedule.

Additional tasks include:

1. Spot checks of satellite SST's against data from two accurate buoys
2. Compare averages of SST fields that are mainly derived from aircraft observations against SMMR derived SST's
3. Compare total precipitable water amount as derived from radiosondes both in the JASIN area and from selected atolls in the Pacific.

This work is supported jointly by NOAA and NASA.

## COASTAL AND ESTUARINE RESEARCH

Principal Investigator: Hongsuk H. Kim  
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Goddard's activities in this area address oceanic phenomena which are observable with NASA's remote sensors. Studies conducted in the past and planned for the future incorporate airborne ocean color, thermal infrared data, as well as Nimbus-7/Coastal Zone Color Scanner (CZCS) data, coupled to field investigations performed by non-NASA oceanographers. Examples of two dynamic and marine biology investigations include collaboration in the South Atlantic Bight and the Grand Banks where the Gulf Stream interacts strongly with the bottom topography to produce a broad spectrum of physical and biological phenomena. Names and affiliations of investigators with whom Goddard has been working include: L. P. Atkinson, Skidaway Institute of Oceanography; Charles Yentsch, Bigelow Marine Research Laboratory; and Paul E. LaViolette, Naval Oceanographic Research and Development Activity.

Significant progress has recently been made in generating chlorophyll gradient maps of large ocean areas from raw ocean color scanner data, after removing the atmospheric effects. Proven correlation between the surface chlorophyll measurement and the derived products was as high as -0.96. A new approach is advocated to apply a delineation technique based on ocean color changes using chlorophyll concentration as tracers of the water masses of underlying layers.

Plans have been made to study intrusions of Gulf Stream water onto the Continental Shelf and slope which result in phytoplankton blooms. Specifically, time-space analysis of upwelling features and total biota of the area will be used to assess the conversion efficiency of phytoplankton to higher trophic levels of interest to fisheries. A corollary study of wave-current interactions in the Grand Banks will be conducted in order to quantify effects which may influence radar backscatter and thus allow frontal detection using active microwave sensors.

## ESTIMATION OF KINETIC ENERGY IN THE NORTH ATLANTIC OCEAN

Principal Investigator: C. D. Leitao, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 577, FTS 928-5577.

Co-Investigator: N. E. Huang, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 357, FTS 928-5357.

Long Term Interests: Our long term interests are directed toward the estimation of the mean and fluctuating statistics of basin-wide ocean circulation using altimetric measurements as a prime data source. However, estimation of global statistics are not feasible at this time because of (1) orbit slope and height uncertainties, (2) geoid undulation precision at short wavelenghts, and (3) overall altimeter measurement precision.

Specific Investigation Objectives: Therefore, our short term objectives are modified to study surface current flow statistics in the Northwestern Atlantic where (1) a gravimetric geoid is known at a 10 km grid size, (2) ground truth data is available for comparison purposes, and (3) orbit slope and bias errors can be minimized by using short arc analyses. Three years of GEOS-3 intensive mode altimeter data is the prime measurement data source.

Approach: Our approach is to construct a three-year mean and standard deviation surface of altimeter data referenced to a precise geoid. The mean surface is an estimate of the mean circulation flow in the region and the standard deviation provides an estimate the variation of the geostrophically energetic areas of the study region. Comparisons will be made with kinetic energy maps produced by Klaus Wyrtki using independent ship drift data. In addition, for months with both good distribution and density of passes, difference surfaces will be computed in an attempt to detect eddy and ring locations. Successive monthly difference surfaces could be used to track eddy and ring movements.

Progress: A three year mean and standard deviation surface have been computed at a  $1/2^\circ$  cell resolution. Results are encouraging and point out certain geoid problems. After further analyses, a final computation will be made using a  $1/4^\circ$  cell size.

Funding: Part of this effort is being performed by Carlos G. Parra of EG&G Washington Analytical Services Center, Inc. Also, a partial support of the effort was provided by the Bureau of Land Management, DOI through an interagency agreement.

## LABORATORY AND FIELD STUDIES OF RELATION OF POLLUTANT-WATER INTERACTIONS TO SPECTRAL RADIOMETRIC SIGNATURES

Principal Investigator: B. W. Lewis  
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The long-term interest has been to develop methodology to enable one to determine, by laboratory measurements, the feasibility of using remotely sensed optical upwelling spectral radiance data for the identification and quantification of pollutants in marine waters.

The objectives are to develop relationships between the field (remote sensing) and laboratory optical measurements which will allow one to predict and catalog remote-sensing spectral signatures for specific marine contaminants from laboratory optical measurements.

The approach involves field and laboratory optical measurements and the relation of these through a simplified radiometric model which was developed by Dr. H. Hodara on a NASA grant to the University of Southern California.

The program is being completed--recent results have produced a methodology involving a characteristic optical parameter ( $\Phi$ ) obtainable from laboratory measurements of spectral reflectance and transmittance of specific contaminant-ocean water solutions and generic clean ocean water reflectance. This parameter which is a function of concentration is used to calculate spectral radiance for various conditions of concentration, sky illumination, and types of ocean water. Thus, feasibility and limitations for the specific contaminant for low-altitude remote sensing can be assessed without recourse to very expensive field tests which also involve sea-truth measurements which are of questionable representativeness. It is planned to write a comprehensive report on the methodology developed within this fiscal year (1980).

## STATISTICAL INTERPRETATION OF SEASAT ALTIMETER DATA

Principal Investigator: Dr. Belinda J. Lipa  
Remote Measurements Laboratory  
Stanford Research Institute International  
Menlo Park, CA 94025

Objective: To develop and apply methods for the leading edge of the Seasat altimeter echo to give the following ocean surface parameters and their statistical uncertainties: swell amplitude, rms wind-wave height and skewness in the surface height probability density.

Approach: The derived probability functions will be interpreted in terms of swell amplitude and from waveheight of wind-derived waves. These results will then be compared with surface truth measurements obtained in the Joint Air-Sea Interaction (JASIN) experiment and the Gulf of Alaska experiment.

Status: Analytical methods have been developed and tested with simulated data.

1. Interpretation of the leading edge in terms of a model of the ocean surface that includes modulated swell and wind-waves.
2. Derivation of ocean surface parameters and their statistical uncertainties by fitting models to the leading edge using the method of maximum likelihood.
3. Integral inversion to give the actual form of the surface height probability density, without the assumption of a model.

By the end of the present contract period (March 31, 1980) we will have completed analysis of Seasat data to give the covariance matrix of the measured waveform and the corresponding statistical uncertainties in estimates of skewness and rms waveheight.

This work is supported jointly by NOAA and NASA.

AN EXPERIMENTAL PROGRAM TO PROVIDE REMOTE MEASUREMENT AND  
ANALYSIS OF OCEAN WAVES, SEA-LEVEL WINDS AND BALANCED  
PRESSURE IN SUPPORT OF SEASAT-A

Principal Investigator: Dr. Joseph W. Maresca, Jr.  
Remote Measurements Laboratory  
SRI International  
333 Ravenswood Avenue  
Menlo Park, CA 94025

Objective: To provide comparative measurements of wind direction, wave direction, and significant wave height made nearly coincidentally in time and space by Seasat sensors and by the SRI-operated Wide Aperture Research Facility (WARF) HF skywave radar and to provide objective analysis of the Seasat-and WARF-derived surface winds and computation of the balanced pressure field from the wind field.

Status: Three data sets have been selected for analysis in which similar geophysical measurements were made by the WARF skywave radar and by Seasat. First, we will compare measurements of winds and waves made by the WARF skywave radar and by the Seasat SASS and Altimeter during an overflight on 3 October 1978. The WARF radar illuminated ocean areas directly below Seasat during this overpass. Second, using objective analysis techniques, we will compute balanced pressure fields for the Eastern Pacific Ocean for 16-17 July 1978 based on the Seasat SASS data and compare these pressure fields to NWS surface charts. Third, we will compare the WARF skywave radar measurements made during Gulf of Mexico tropical storm Debra (August 1978) with Seasat SASS and Altimeter measurements when the Seasat data become available.

Specific time-space windows for coincident and nearly coincident Seasat-WARF data records have been established and preliminary processing of both the WARF and Seasat data has been completed. Existing computer software has been modified and new software has been developed to facilitate objective analysis of the WARF-Seasat measurements.

This work is supported jointly by NOAA and NASA.

## OCEAN CIRCULATION AND TOPOGRAPHY

Principle Investigator: James G. Marsh, Geodynamics Branch  
Goddard Space Flight Center, Greenbelt, MD 20771  
Phone: 301-344-5324 (FTS 344-5324)

### Long Term Interests

To provide a physically unambiguous basis for the interpretation and quantitative utilization of satellite altimetry observations of sea surface topography and to assess the impact of this on relevant problems in oceanography. To develop analytical and interpretative techniques for determining the contributions of the ocean geoid, tides, barotropic effects and dynamic topography due to general and mesoscale ocean circulation phenomena to satellite radar altimeter measurements of the sea surface geometry. To conduct simulations and real data analyses, to identify and formulate ways of achieving improvements in the computation of satellite orbits so that global orbital accuracies of 20 cm. or better can be achieved.

### Specific Investigation Objectives

The specific objectives of the present work are to develop maps of the mean sea surface topography from satellite altimeter data and to use these data to derive information on dynamic ocean processes. In support of the computation of the sea surface topography, the orbits of GEOS-3 and Seasat are being studied in great detail in order to provide more accurate determinations of the satellite positions which are required for the analyses of the altimeter data.

### Approach

Models for the major perturbing forces on Seasat and GEOS-3 are being assessed and techniques for either improving the models or minimizing the model error are being implemented. During the past year, Seasat radial orbit errors have been reduced from about 10 meters to about a meter through force model improvements. The orbits computed using the upgraded models are being combined with the altimeter data and the data are being gridded and contoured in the form of topography maps.

### Status

Global maps of the mean sea surface topography have been computed by combining the GEOS-3 and Seasat altimeter data with the most accurate orbits we have been able to compute. The data presented in the contour maps has also been prepared on magnetic tape in the form of a  $1^\circ \times 1^\circ$  grid. The r.m.s. difference between the two maps is currently 1.7 m.

## THE USE OF NIMBUS-7 IMAGERY TO STUDY THE BERING SEA ICE

Principal Investigator: Dr. Seelye Martin  
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University of Washington  
Seattle, WA 98195

Objective: Use an existing sea-ice program (OCSEAP) to provide surface truth for evaluation of the NIMBUS-7 SMMR for characterization of ice cover in the Bering Sea.

Approach: Four different observational scales have been employed: SMMR images; aircraft overflights, surface observations from the NOAA ship SURVEYOR, and laboratory modeling.

The SMMR and the VIR will provide large-scale images of the ice for determination of the distribution of ice types and the large scale response of the ice to winds. Altimeter data will also be looked at to see if it yields meaningful information about either long waves propagating into the pack, or pressure ridge statistics.

Surface truth data has been obtained at the ice edge between Nunivak and St. Matthews Islands during March 1979.

Status: First, based on the data from our Bering Sea cruise, we wrote an article entitled "Field observations of the Bering Sea ice edge during March 1979" for *Monthly Weather Review*.

Second, two months of the SMMR data have been selected for processing by January 1980. One of the selected months is the period February 15 to March 15, 1979, which includes the period of our cruise. Based on this good news, we hope that by March 1980, we will be able to examine maps of brightness temperature for the Bering Sea.

This work is supported jointly by NOAA and NASA.

## SATELLITE SEA SURFACE TEMPERATURE DETERMINATION

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Attempts to provide satellite derived infrared sea surface temperature determinations on a global scale still produce  $\pm 1$  K to  $\pm 4$  K errors when compared with research ship bucket temperatures. An error analysis using dual visible (0.5-0.7  $\mu$ m) and infrared (10.5-12.5  $\mu$ m) data suggests the following causes for a mesoscale region such as the Gulf of Mexico: Radiometric-thermometric differences  $\pm 0.4$  K to  $\pm 0.5$  K; Neglecting surface (Fresnel) reflection  $\pm 0.5$  K; Radiative transfer corrections  $\pm 0.4$  K to  $\pm 0.6$  K; Cloud contaminated infrared pixels  $\pm 0.5$  K; NEAT of instrument  $\pm 0.2$  K. Preliminary tests show that the overall error can be reduced to  $\pm 0.5$  K in a mesoscale region if select surface observations are incorporated in the analysis. To achieve this accuracy the satellite data is remapped into a rectangular matrix at full resolution, clouds are eliminated using an objective discriminant function based on Bayesian statistics, atmospheric absorption and re-emission is accounted for using the LOWTRAN-4 radiative transfer model on cloud free or equivalent cloud-free radiosondes from stations on the study area's periphery, spacecraft data are calibrated using environmental data buoy or research ship sea surface temperatures, and finally, daily maps are composited to eliminate gaps due to clouds. Depending on cloud conditions, 10 km resolution maps covering  $10^6$  km<sup>2</sup> areas of the western North Atlantic Ocean are produced every three to five days.

The NASA co-sponsored sea surface temperature effort is in cooperation with Dr. Allan Robinson of Harvard University, the Goddard Space Flight Center, and is part of the U.S. POLYMODE program. Initial funding for the work (in the Gulf of Mexico) is from the U.S. Department of Energy's Ocean Thermal Energy Conversion Program. Journal publications of remote sensing results is planned for Remote Sensing of Environment for 1980; oceanographic analysis for geophysical results is planned for FY80 and 81 and will be published at a later date.

## MARSEN DATA ANALYSIS

Principal Investigator: J. T. McGoogan, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 405, FTS 928-5405.

Long Term Interests: To extract scientific and engineering information and demonstrate remote sensing capabilities from the MARSEN data obtained with the Wallops Flight Center (WFC) altimeter and airborne oceanographic lidar (AOL) instrumentation.

Specific Objectives: (1) Recover waveheight skewness from the altimeter data in the presence of known surface drift currents. (2) Obtain off-nadir altimeter waveforms for use in designing future ice tracking and multibeam altimeters. (3) Evaluate the AOL in the fluorosensing mode for the detection of ocean fronts. (4) Test the AOL's performance in the detection and measurement of thin film monomolecular layers in the ocean surface. (5) To evaluate the AOL chlorophyll *a* fluorescence measurements by comparison with the German research vessel (R.V.) Tabasis truth data. (6) To evaluate the AOL conical scan sea surface height data for extraction of directional sea state.

In addition we intend to supply corroborative oceanic data to other MARSEN investigators.

Approach: It is first planned that the airborne and all supporting data be reviewed to determine the potential of the entire set. The most promising data then will be given the most attention. The altimeter investigators will be Dave Hancock (WFC) for the altimeter with Dr. Gary Brown of Applied Sciences Associates helping to interrupt the data. The AOL investigator will be Dr. Frank Hoge (WFC) and he will be assisted by Bob Swift of EG&G in analysis interpretation of the data. All AOL chlorophyll *a* work will be done in collaboration with the German scientist Dr. Roland Doerffer of the Institut für Werkstofftechnologie und Chemie. The monomolecular layer work is all being done in cooperation with the Naval Research Laboratory. Scientific results will be published and engineering results documented and supplied to the appropriate personnel.

Progress: A first cut reduction of the data has been done and the off-nadir altimeter data, the AOL oceanic fronts and the AOL thin film data looks very promising.

ADVANCED OCEAN SENSOR SYSTEMS DEVELOPMENT

Principal Investigator: J. T. McGoogan, NASA Wallops Flight Center, Wallops Island, VA 23337. (804) 824-3411, Ext. 405, FTS 928-5405.

Long Term Interests: To develop oceanic sensors for future NASA airborne space missions. These efforts presently involve altimetry, surface contour radar and wave motion sensor and related technology. It is desired that these techniques be further developed to provide increased resolution, accuracy and coverage and that an overall plan be produced.

Specific Objectives: 1) To develop adaptive resolution techniques for altimetry that will increase the tracking flexibility for land and ice and provide higher resolution for oceanic surface mapping. 2) To further develop the multibeam altimeter concept to provide more rapid mapping of the ocean surface height. 3) To explore the potential of the wave motion concept as a means of detecting ocean currents. 4) To develop an aircraft and shuttle test plan for testing these new sensors and other related concepts and hardware improvements.

Approach: This effort is primarily being conducted with Dr. Ed Walsh (theoretical models); Craig Purdy (hardware); W. A. Brence (overall plans) of Wallops directing the work and developing the overall plans and Johns Hopkins Applied Physics Laboratory investigators Dr. John McArthur (altimeter); George Bush (wave motion sensor and multibeam); Dr. Chuck Kilgus (overall program plans) are conducting the major supporting studies. Dr. L. S. Miller of Applied Sciences Associates, Inc. is independently reviewing the multibeam concept. Also it is planned that other radar ideas of Dr. Don Barrick (NOAA, Boulder), Fred Jackson (NASA GSFC) and Dr. Linwood Jones (NASA LaRC) will be incorporated into the overall plans for a shuttle testing of altimeter related new techniques.

Progress: APL has recently completed a study of the wave motion sensor. The multibeam altimeter has been analyzed by both Wallops and APL personnel and a contract issued to Applied Science Associates for an independent review.

## COASTAL & ESTUARINE RESEARCH

### PRINCIPAL INVESTIGATOR:

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The long term objective of this research is to develop the use of ocean color and temperature sensing from space as a reliable tool for oceanographic research. Principal applications will relate to studies of phytoplankton patchiness, ocean fronts, and other mesoscale ocean phenomena. We are pursuing three parallel investigations using Nimbus-7 CZCS data:

- 1) We are collaborating with the CZCS Nimbus-7 Experiment Team (NET) to empirically verify and tune algorithms for estimating useful maps of oceanographic parameters (e.g. chlorophyll and diffuse attenuation coefficients  $k$ ) from CZCS image data. We are working most closely in this effort with Dr. H. R. Gordon of the University of Miami, and Mr. D. K. Clark of NOAA NESS. Our primary sample of shipboard optical, phytoplankton pigment, and suspended matter measurements, made concurrently with CZCS observations, was obtained by Clark using NOAA funds.
- 2) We and Dr. Charles Yentsch (of Bigelow Lab. for Ocean Sciences) are combining time sequences of CZCS data and research vessel cruise data to describe the time varying patterns of phytoplankton bloom patchiness in the Gulf of Maine and over George's Bank. If Nimbus-7 continues to operate, we hope to analyse up to three complete annual bloom cycles. Dr Timothy Kao (of Catholic University) is also participating in this investigation by modeling the effects of the spring runoff front on phytoplankton distribution in the Gulf of Maine.
- 3) We and Dr. Paul LaViolette (of NORDA) are analysing CZCS images of the persistent, but complex, system of ocean fronts overlying the outer Grand Banks. Through comparisons with AXBT and STD sections (both historical and concurrent with CZCS observations), and with simulations by ocean fronts models, we seek to explain the markedly different ocean front signatures we observe in the visible, as contrasted to infrared, channels of the CZCS.

These investigations are in early-to-intermediate stages of data analysis. Nevertheless, preliminary algorithm validation results will appear in two forthcoming reports on CZCS which have been accepted for publication in Science.

## TIDES FROM SATELLITE ALTIMETRY

Principal Investigator: M. E. Parke  
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One of the major potential uses of satellite altimetry data lies in the mapping of global ocean tides. Because of the spacial coverage provided by satellites, such altimetry data contain information on the spacial structure of tides difficult to find from conventional single point measurements. Throughout much of the world's oceans, though, the length scales of tides and radial orbit errors are similar, and thus separation of tides from orbit errors becomes difficult.

Therefore in order to investigate how far one can go toward solving for the global tide using existing data sets, it is useful to start with a region where the above limitation does not apply. One such region is the Patagonian shelf off Argentina. The dominant length scales of the semi-diurnal tides here range from 100-1000 km, with a typical amplitude change under a single along the shelf ground track of approximately two and half meters. The radial orbit error in these length scales has been estimated at less than 10 cm for a simulated orbit (Cutting, Born, and Frautnik, 1978, JAS, XXVI, 315-342).

The immediate objectives of this project are centered on solving for the tide on the Patagonian shelf. Corresponding to this solution will be developed a numerical model of the tides over the shelf region. One important objective will be to attempt to estimate the tidal dissipation over the shelf. Based on the results of this project, an estimate will be made of how much of the world's tide can currently be solved for using existing data sets and how much improvement is needed to solve for the complete global tide. The final version of the SEASAT data set should be distributed in a few months time, and analysis will begin at that time.

## TROPICAL PACIFIC STUDIES

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The major currents in the world's oceans are important to shipping, the distribution of marine organisms, and the distribution of physical properties in the ocean. Variations in the sea surface temperature (SST) have been indicated, through air sea interaction, to have a decided influence on regional weather. The ocean currents determine the ocean contribution to the poleward heat flux, and hence to the global heat budget, and thus to long term climate. Because of the spacial coverage of satellites, satellite altimetry is in a unique position to provide information about the major ocean currents. Past and present studies elsewhere for the regions of the Gulf Stream and Kuroshio have shown features that appear to correspond to ocean currents and eddies. However, the range of applications toward describing and understanding the current systems and the usefulness of satellite altimetry for inferring surface currents has yet to be fully defined. It is important that these areas be investigated to provide input for the next generation of satellite missions.

This project is developing into three main areas. The first is a joint project with R. Bernstein at Scripps Institution of Oceanography, and involves looking at the near equatorial Pacific for 30 day, 100 km wavelength equatorial waves predicted by Cox (1979, Ocean Modelling, 28, 1-4). If these waves fulfill the same function in the real world as in the model, then they will be important to the near equatorial heat transport and near equatorial air sea interaction.

The second is a joint project with J. Bruce at the Woods Hole Oceanographic Institution, and involves looking at the development of the large eddy in the northern Somalia Basin during the SEASAT lifetime. This eddy spins up under the southwest monsoon from May to October each year. In the long run, understanding of this system should be important to the understanding of how major current systems spin up.

The last is a joint project involving D. Chelton who will be joining JPL soon from the Scripps Institution of Oceanography, and J. Baker of the University of Washington. This work will involve an intercomparison of SEASAT data with bottom pressure gauge measurements in the Drake Passage between South America and Antarctica.

USE OF SEASAT ALTIMETER DATA FOR THE IMPROVED DETERMINATION  
OF THE GEOID, GRAVITY ANOMALY FIELD AND SEA SURFACE TOPOGRAPHY

Principal Investigator: Richard H. Rapp  
Department of Geodetic Science  
The Ohio State University  
Columbus, OH 43210

Objective: Determination of more reliable values of ocean gravity and ocean geoids than are available from GEOS-3, using Seasat's better accuracy and coverage.

Approach: We intend to use the Seasat altimeter data for geoid and gravity anomaly computations, as well as sea surface topography detection if sufficiently accurate geoid information is available. We plan to do global solutions to improve results found from GEOS-3 data. Emphasis, however, in the initial stage of the work will be in areas where GEOS-3 data was sufficiently dense for comparison purposes, and then in areas lacking GEOS-3 data.

Status: We have received some Seasat data to work with, the latest data set being a 15 day data set. We now have programs to read the tape and put the data in a special format developed for processing GEOS-3 data. The inability to get sufficient data for our planned research has seriously hampered our effort. We cannot carry out our work until sufficient data becomes available. We have now been informed that final altimeter data will not become available until February-March 1980, and then we are not sure of the data distribution. We will work with existing data to check out software in preparation for receipt of final form data in March 1980. Upon receipt of the new data actual solutions will be carried out subject to time and funding limitations.

This work is supported jointly by NOAA and NASA.

OPTIMIZATION OF ACOUSTIC BACKSCATTER TECHNIQUES  
TO MEASURE CURRENT PROFILES FROM MOVING VESSELS

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For several years the principal investigator and Dr. Russ Davis (University of California, San Diego) have been working with AMETEK/Straza Division to develop a profiling acoustic current meter with funding from NASA and the Office of Naval Research. A short acoustic pulse is transmitted from the ship and the relative current is determined by observing the Doppler shift of the echo returned from plankton drifting in the water; time-gating the return allows the velocity to be determined as a function of depth. With the addition of high accuracy navigation of the ship, the relative velocity between water and ship may be converted to the absolute current velocity over the earth. We seek to resolve current structures with horizontal scales of 1 or 2 kilometers to a depth of 200 meters or more. Data of this type would be particularly valuable to air-sea interaction studies and to aid in the interpretation of images simultaneously obtained with synthetic aperture radar.

Experience to date reveals the potential of the technique is limited by problems with acoustic signal processing, determination of the ship's velocity over the earth, and contamination of relative velocity by wave-induced motions of the ship. Each of these areas will be attacked by those having expertise in the particular area; all work is to be supported by NASA.

AMETEK/Straza Division is studying the acoustic processing and plans to construct a significantly "smarter" and more flexible instrument. We will continue to work on the wave-induced ship motion problem.

Determination of the absolute ship's velocity is being worked on under a separately supported task: IN SITU VERIFICATION INSTRUMENTATION, EQUIPMENT and SUPPORT (RTOP 146-40-16), by David Rubin at the Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91103.

A Litton LTN-51 Inertial Navigation System (INS) was installed aboard the University of California research vessel, "Thomas Washington." An interface unit was designed and fabricated which enabled the ARINC velocity and position outputs of the INS to be logged by the shipboard computer. The LTN-51 will be replaced during this fiscal year by an improved system including a more modern INS and a Global Positioning System (GPS) receiver, the latter to be supported by ONR. Integration of the GPS receiver and its use will be in cooperation with Columbia University's Lamont-Doherty Geological Observatory.

Analysis of ship motion data obtained in June, 1979, is underway as well as ocean current data taken in January, 1980.

DYNAMICS AND EVOLUTION OF GULF STREAM MEANDERS  
AND MID-OCEAN EDDY CURRENTS

Allan R. Robinson, Division of Applied Sciences,  
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Research directed towards a systematic description in modern scientific terms of ocean currents and related physical fields in an arbitrary large block of open ocean  $0(10^2-10^3 \text{ km})$ . The desired description consists of the best possible statement of the governing dynamics, the statistics of past observations, the present synoptic state of the system, and a forecast of its evolution. It includes interaction with the overlying atmosphere and the surrounding waters. Optimal estimates are made by combining dynamical and statistical model forecasts with information obtained from a real-time observational network so as to minimize pre-selected error norms. Satellite observations (altimetry, SST, fluxes) together with ground truth and subsurface measurements ((A)XBTs, sofar floats) constitute a feasible, conventional observational system. The dynamical model serves not only to summarize physical knowledge and as a tool to explore novel dynamical processes, but also importantly as an interpolation and extrapolation scheme for the observations, and as an interpretative device for relating sea surface information to subsurface currents and related fields. Specifically the research is related to the western North Atlantic, a region of strong variable currents, eddy energy production, conversion and transmission, vigorous air-sea interactions, and considerable practical human activity. The dynamical model is a quasigeostrophic open-ocean model with a mixed layer model attached to the top. The barotropic version has been used for dynamical-forecasting simulation studies with realistic fields; sensitivity to boundary updating frequency and lack of sensitivity to the vorticity specification were discovered. Statistical forecasting with mixed space-time objective analyses and optimal updating with interior data are underway. The baroclinic version has been successfully run on idealized fields and is entering the simulation phase. The non-linear mixed-layer model is under construction; preliminary analytical process studies are nearly complete. The POLYMODE field data set (including an extensive set of SST measurements by XBT's) combined with available satellite observations will first be modelled and described, and then the region extended to include the meandering Gulf Stream and ring region. We are collaborating with Dr. G. Maul (NOAA, AOML) in the analysis and modelling of satellite SST in these regions and with Mr. N. Huang (NASA Wallops Island) for altimetry data. Interaction with scientists at NASA Goddard SFC is ongoing both because of specific overlapping interests and because of the expertise in Dr. M. Halem's group in analogous problems in atmospheric modelling, e.g. in modelling and data assimilation techniques. This research is supported approximately  $\frac{1}{2}$  NASA,  $\frac{1}{2}$  ONR, exclusive of computer time.

INVESTIGATE THE TIME EVOLUTION OF THE CORRELATION  
BETWEEN BATHYMETRY AND THE GEOID HEIGHT IN THE  
PACIFIC OCEAN

Principal Investigator: Dr. Micheline C. Roufosse  
Smithsonian Institute Astrophysical  
Observatory  
Cambridge, MA 02138

Objective: Study the flexural rigidity of the lithosphere, and relate it to the age of the region estimated from magnetic data. This study will be based on bathymetry and geoid heights determined from altimeter data.

Approach: In a recent effort, the relationship between the geoid heights derived from the GEOS 3 altimeter and ocean bathymetry has been studied around the Hawaiian Emperor Seamount chain. Using the thin plate model approximation (McKenzie and Bowin, 1976), a theoretical filter has been calculated in wave number space with variable values for the flexural rigidity of the lithospheric plate. That filter has then been Fourier transformed into normal space and convolved with the bathymetry to predict the geoid heights. The value for the flexural rigidity which best accounts for the observed geoid is determined. This method has proven quite successful in predicting the wavelength, intensity and shape of the observed geoid heights and will be used in this study.

Status: Most of the work achieved so far has dealt with the organization and editing of the Seasat radar altimeter data. Most of the data obtained to date have been limited to the Northern Hemisphere but data in the Southern Hemisphere are now available for a 12 day period and have been requested.

The test area chosen in the Pacific Ocean is Hawaii; an extensive study of that area has been done here in collaboration with Dr. B. Parsons (MIT) using the GEOS 3 radar altimeter data and has given excellent results. Ninety Seasat passes have been retrieved, plotted, and edited in that region in order to assess in a known case the gains in accuracy offered by Seasat and thus give a better feel for the steps to be taken next.

This work is supported jointly by NOAA and NASA.

## MICROSCALE ICE DYNAMICS AND PROCESSES

Principal Investigators: Ronald J. Schertler  
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The long range goals of this subprogram are to determine and characterize active microwave remote sensing methods and sensor combinations capable of measuring ice properties at the necessary temporal and spatial frequencies.

The specific investigation objectives are to develop and evaluate analytical and quantitative interpretation techniques for utilizing remote active microwave observations to obtain information on (1) microscale ice properties and features such as age, type, floe size, distribution, surface roughness characteristics including pressure ridges and dynamic motion, and (2) iceberg and ship detection and discrimination.

The approach will be to conduct data reduction and analysis of aircraft microwave data collected in the field experiments in the Arctic and North Atlantic in FY '78 and '79. Active microwave data products will be distributed to and analysis results will be co-ordinated with various scientific coinvestigators in these field experiments.

Scientific coinvestigators:	Dr. W. W. Weeks Cold Regions Research and Engineering Laboratory Hanover, New Hampshire
Dr. W. L. Jones Dr. C. Swift NASA Langley Research Center Hampton, Virginia	Dr. Rene O. Ramseier Atmospheric & Environment Service Downsview, Ontario, Canada
Dr. R. E. Stanley NASA Wallops Flight Center Wallops Island, Virginia	Dr. F. Deily Alaska Oil and Gas Association

In addition, Dr. W. D. Hibler III, of Cold Regions Research and Engineering Laboratory, is being funded under a contract for Developing a Sea Ice Dynamic/Thermodynamic Model.

## THE IMPACT OF ALTIMETER DATA ON THE CALCULATION OF OCEAN CIRCULATION

PRINCIPAL INVESTIGATOR: Dr. Paul S. Schopf, Code 912  
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This study is aimed at assessing the impact of high quality sea surface topography data on the prediction and diagnosis of the ocean circulation, primarily in the upper ocean. Since the surface pressure field is an important determinant of the upper water flow, we are interested in the following questions about ocean diagnosis:

- How well can the classical "level-of-no-motion" geostrophic theory be expected to perform as a function of geographic location and time-averaging period.
- How much of an improvement can radar altimetry be expected to make.
- How deep into the water column will detailed information from the surface pressure be noticeable.

This study is a new effort and no results have yet been obtained. Activities include analysis of existing in-situ data and model based impact studies, assessing the impact of hypothetical altimetry information on the diagnosis of model results.

This work is undertaken as a collaborative effort between Dr. Schopf and Dr. D. Harrison of M.I.T. Computer support is being furnished by the Modeling and Simulation Facility of GLAS.

DETERMINATION OF A PRECISE SEASAT EPHemeris AND OCEAN TOPOGRAPHY  
USING LASER AND ALTIMETER MEASUREMENTS FOR MODEL IMPROVEMENTS

Principal Investigator: Dr. Bob Schutz  
Aerospace Engineering and Engineering  
Mechanics  
University of Texas at Austin  
Austin, TX 78712 (512) 471-1356

Objective: Determination of a continuous long duration orbit using laser and altimeter data, resulting in an improved force model for use in determining Seasat orbits at other times and for the determination of the ocean topography.

Approach: This objective will be achieved through extensive force model evaluation and through the simultaneous estimation of geopotential coefficients and other appropriate model parameters. The altimeter measurements will be used in computing the gravitational forces and an equipotential surface.

Status: A review of the altimeter data coverage has resulted in the selection of the period July 26 to August 15, 1978, as a first priority data set. Consequently, major efforts have recently concentrated on collecting all of the known laser range data for this priority period, applying appropriate corrections, and editing inconsistent measurements. Similarly, the altimeter IGDR set containing approximately one measurement per second has been reviewed and overland points have been edited. A single long orbit of 21 day duration for this priority time period has been analyzed to evaluate the current limiting parameters in the computation of a precise ephemeris. As part of this phase, estimates of geopotential coefficients have been obtained for selected experimental sets. These include resonance coefficients, e.g.,  $C_{43,43} = 3.8 \times 10^{-8}$  and  $S_{43,43} = 4.0 \times 10^{-8}$  were estimated which produce an orbital perturbation with a 17 day period. Estimation of a large parameter set to improve the force model is nearing completion using laser data alone as well as using laser and altimeter data together.

Preliminary analysis of the altimeter data has been performed also. Using three day orbits during the first 12 days of the priority period, simultaneous estimates have been obtained for the altimeter time tag correction ( $\tau$ ), the equatorial radius ( $a_e$ ) and the reciprocal flattening ( $1/f$ ) of the earth. The results, based on 668,000 altimeter measurements, include  $\tau = 71.4$  ms,  $a_e$  approximately equal to 6,378,138 m, and  $1/f = 298.273$ . The reciprocal flattening is higher than other determinations and may reflect a seasonal surface feature or an orbit error.

This work is supported jointly by NOAA and NASA.

MESOSCALE OCEAN DYNAMICS - INVESTIGATION OF CAPILLARY AND SHORT GRAVITY WAVES

O. H. Shemdin and D. D. Evans, Jet Propulsion Laboratory,  
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Long term interest: To understand the dynamics of capillary and short gravity waves and their dependence on wind speed, long ocean waves, current, atmospheric stability and surface contaminants.

Specific investigation objective: To develop sufficient insight on the modulation of short waves by long waves to enable determination of the SAR system transfer function.

Approach: Measurements were obtained during the MARSEN and West Coast Experiments with a high response laser-optical sensor which was mounted on a wave follower. The system allowed insitu detection of short wave modulation along profile of long waves. Comparison with Doppler radar measurements at the same site required demodulation of wave slope data that was induced by orbital velocity of long waves.

Progress: (1) It is established that modulation of short waves by long waves is an important mechanism by which SAR forms wave images. Other important mechanisms under investigation are surface slopes, orbital velocity and acceleration of long waves. (2) An algorithm is developed which incorporates a complex orbital dispersion of short waves to relate wave numbers to wave frequencies. (3) The modulation of short waves by long waves has a maximum on the leeward slope of long waves and a minimum on the windward slope. (4) The magnitudes and phases of short wave modulations depend on short wave length, wind speed, orbital velocity of long waves and the shape of the short wave spectrum. (5) Shapes of high frequency wave spectra obtained with the laser-optical sensor compare favorably with those derived with optical techniques.

Other funding: None.

MESOSCALE OCEAN DYNAMICS - WAVE TRANSFORMATION IN FINITE DEPTH  
WATER

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Long term interest: To understand the processes of wave transformation in finite depth water including the sheltering effect of islands. Such insight is required to establish relationships between the deep water wave climate and corresponding near shore wave activity in different physiographic regions of the coast.

Specific investigation objective: To demonstrate that SAR can provide useful information on wave dynamics in finite-depth water through comparisons with insitu measurements of the directional wave height spectrum.

Approach: Conduct collaborative experiments with clearly established oceanographic objectives involving both sensor scientists and oceanographers. Two such experiments have been completed to date:

- (1) MARINELAND Experiment - This experiment was designed to investigate wave-current interaction in the Gulf Stream and across the Florida Atlantic Shelf offshore of Marineland, Florida. Scientists from 15 institutions participated. An overview paper is published in EOS (1980) describing the various objectives and results.
- (2) WEST COAST Experiment - This experiment was designed to investigate wave sheltering by islands in the Southern California Bight region. Extensive use of remote sensing and conventional techniques were incorporated. Scientists from 23 institutions participated. An overview paper describing the various objectives and results is published in EOS (1980).

Progress: (1) It is established that SAR provides reliable information on dominant surface wave lengths and directions. (2) It is not established yet that SAR can provide information on wave height. This is the subject of parallel research in progress. (3) Wave information provided by SAR is useful in defining such wave transformation processes as wave refraction, wave defraction and non-linear interaction. (4) Significant insights are gained through the use of SAR and insitu data in conjunction with wave numerical models to understand the contributions of such effects as friction, percolation, bottom motion, nonlinear interaction, shoaling, refraction, and island sheltering on wave transformation in finite depth water.

Other funding: Various institutions participating in MARINELAND and West Coast Experiments provided their own funds. The JPL effort was partially supported by NSF and ONR funds.

## SAR OCEAN REMOTE SENSING STUDIES

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The long term objective of this research is to demonstrate the utility of SAR to provide information pertaining to waves, currents, frontal features, wind, and air/sea temperature of the oceans. Specifically, theoretical studies and algorithm development is needed to perfect the utility of SAR for oceanographic use. Since the SAR imaging of gravity waves has been studied in detail, progress in this area in respect to defining SAR limitations of detection of gravity waves has been significant. The SAR ocean remote sensing question that has not received a lot of attention is the question of frontal feature detection.

ERIM plans to work closely with Dr. Russell Davis of Scripps Institute of Oceanography to collect SAR data over frontal features off the West Coast of the United States. Dr. Linwood Jones of NASA Langley will also participate in the experiment along with other NASA investigators using both active and passive microwave devices. In addition to mapping frontal features and their associated currents, the SAR will be further evaluated in respect to detection of wind fields and air/sea boundary conditions. Comparisons of SAR with the other microwave remote sensors will also be made. An experiment is also planned in cooperation with Dr. Mel Briscoe of Woods Hole Oceanographic Institute to study the Gulf Stream and its resulting eddies in detail.

The ERIM SAR system to be used in these experiments is a calibrated radar backscatter device that images simultaneously at X- and L-band (3 and 23.5 cm) wavelengths with both parallel and cross polarization. Digitally processed X-band data is available in real time.

NASA is supporting an investigation this year to properly plan the West and East Coast experiments. To better understand the interaction of SAR with the ocean frontal features, SEASAT SAR data collected off the West Coast and Gulf Stream are being processed and analyzed. The analysis includes both Doppler sensitivity measurements as well as relative  $\sigma_0$  (radar backscatter measurements).

The presently funded ERIM activity is also designed to help define a future microwave oceanographic sensing system and provide technical consultation to NASA and ONR regarding proposed microwave oceanographic microwave measurement activities. This task involves consideration of advanced SAR systems and data processing techniques that can be implemented by NASA for shuttle, other appropriate satellites, or aircraft systems.

## DETECTION OF OCEANIC CURRENTS USING SEASAT SAR DATA

Principal Investigator: Dr. Robert A. Shuchman  
Environmental Research Institute of  
Michigan  
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Ann Arbor, Michigan 48107

Objective: Investigate techniques for detection of oceanic current motion by measurement of the SAR azimuthal Doppler frequency shift. This shift is caused by radial (line of sight) velocities. Results of this study will be the evaluation of an algorithm for current measurements using SAR. Included in the evaluation are measurement accuracy estimates, and currents values for the test areas.

Approach: Experimental "sea truthed" sites in the Gulf Stream, Columbia River, Vancouver Island area, and the English Channel were chosen for study. These test sites provided both ebb and flood conditions, with current velocities ranging from 0.5 to 8 m/sec. Stationary land targets, located near the ocean test sites will be measured to obtain a reference for the Doppler shift data. Doppler information from over the ocean test sites will be examined and measured for both SEASAT and aircraft cases.

Status: Both theoretical studies and actual measurements have been considered. The relative contributions to this shift by currents, gravity wave orbital motions, and capillary phase velocities are being studied by a theoretical model now under development. The investigators (F. I. Gonzalez and C. L. Rufenach of NOAA are aiding ERIM), using both aircraft X- and L-band and SEASAT L-band SAR, measured the Doppler shift of moving ocean scatterers relative to stationary scatterers. The measurements to date have indicated the Doppler method can successfully predict direction of currents, but the absolute magnitude is still under study. The analysis further indicates the SEASAT L-band SAR system is not an optimum design to measure currents, due to frequency and viewing angle (geometry) considerations.

This work is supported jointly by NOAA and NASA.

## SEASAT SAR COASTAL OCEAN WAVE ANALYSIS

Principal Investigator: Dr. Robert A. Shuchman  
Environmental Research Institute of  
Michigan  
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Ann Arbor, Michigan 48107

Objective: The purpose of this study was to evaluate the utility of SEASAT SAR to image coastal wavefields. Coastal gravity waves imaged by the SEASAT were further evaluated in terms of providing bathymetric and bottom topographic information. Bathymetric information was gained by extracting wavelength and wave refraction information from coastal gravity wavefields and reducing this data to water depths using classical oceanographic wave refraction theory. The presence of deep water bottom topographic features can be inferred in some cases by examination of internal wavefields visible on the SAR imagery.

Status: Wave refraction was documented on Rev. 974 (Cape Hatteras) data when an 11-second swell was detected by the SAR and successfully tracked from deep water to the coastline. The SEASAT data favorably compared to a graphically constructed wave refraction diagram that utilized bottom topographic information. Additionally, depths were calculated by comparing deep and shallow water wavelengths. Predicted versus actual depths produced significant statistical correlations ( $R = 0.80$ ).

The Rev. 762 data (Cape Wrath, Scotland) exhibited an 11.5-second swell pattern that could not be explained through wave refraction and bottom topography effects. Instead the wave patterns observed here were the result of diffraction caused by an island approximately 30 km outside of the SAR pass.

A final report has been submitted.

This work is supported jointly by NOAA and NASA.

SHIP AND SATELLITE BIO-OPTICAL RESEARCH IN THE CALIFORNIA BIGHT  
(Raymond C. Smith, Scripps Institution of Oceanography, University of California, La Jolla, California 92093, 714-294-5534).

A long term objective of this research is to increase our understanding of primary production by observing, and subsequently modeling, phytoplankton responses over a full range of spatial and temporal scales for an oceanographic region.

Specific objectives include a quantitative assessment of the spatial and temporal variability (patchiness) of chlorophyll over the entire California Bight region which will be used: to study the physical and biological processes leading to chlorophyll variability; to investigate the ecological and evolutionary significance of this variability, and its relation to the prediction of fish recruitment and the abundance of marine mammals; to investigate how phytoplankton patchiness effects our ability to detect significant spatial and temporal changes in abundance; and to study physical and biological phenomena that manifest themselves by changes in near surface chlorophyll concentrations including red tides, island mass effects, upwelling and excursions of current boundaries.

Our approach is to use complementary ship and satellite (Nimbus 7 - CZCS) bio-optical data. The satellite data are obtained from NASA or, alternatively, received directly at the Scripps Remote Sensing Facility (funded jointly by NASA, ONR and NSF). Shipboard bio-optical data have been obtained on a no-cost-not-to-interfere basis on oceanographic ships doing biological studies in the California Bight (primarily, but not exclusively, on NOAA/NMFS ships).

Significant results (in collaboration with La Jolla NMFS) include correlations observed, in both ship and satellite data, between areas of high chlorophyll concentration and the distribution of several species of marine mammals.

The Visibility Laboratory's remote sensing capability, which is heavily used in this research, has been funded by NOAA/NESS.

USE OF NUMERICAL CONTINENTAL SHELF CIRCULATION  
AND POLLUTANT TRANSPORT MODELS FOR ANALYSIS  
OF REMOTELY SENSED DATA

Principal Investigators:

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Dr. Peter C. Cornillon  
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In cooperation with NASA Langley Research Center, research is currently in progress assessing the use of remotely sensed information in providing input and verification data for three dimensional continental shelf and coastal seas circulation and pollutant transport models. The present goals are identifying where the links between remote sensing and modeling can be made, the limitations for more extensive coupling and illustrating the linkages for several cases where remotely sensed data products exist.

Extensive work has been performed in designing a set of three dimensional hydrodynamic and material transport models that can readily accept remotely sensed information but at the same time minimize computational requirements. SEASAT scatterometer and altimetry and NIMBUS 7 CZCS data have been obtained for the Georges Bank/Gulf of Maine study area and software developed to process the data. Based on a comprehensive review of the available imagery and in situ physical oceanographic measurement programs two time periods have been selected for testing the linkages. During the first period SEASAT radar altimeter data, along two track lines, and scatterometer data, over the entire region, are available for a several day period. The second period selected has visible and thermal imagery from CZCS and shows an unidentified surface feature being advected through the study area over a 10 day period. Limited in situ data is available for both test periods from BLM environmental baseline studies.

Application of the three dimensional model to tidal circulation dynamics of the Georges Bank/Gulf of Maine area shows reasonably good agreement with observed tidal height records. Interfacing of model predictions for tidal variations to SEASAT altimetry is currently in progress and the results will be reported at the 14th International Symposium on Remote Sensing of Environment.

## MEASUREMENT OF OCEANIC RAINFALL USING SEASAT-A DATA

Principal Investigator: Dr. Robert H. Stewart  
Scripps Institution of Oceanography  
University of California  
La Jolla, CA 92093

Objective: Test theories relating rainfall and microwave radiometric brightness with JASIN data set consisting of shipboard rain data and SMMR radiometric measurements. Parameterize the variables so that ultimately satellite measurements can be converted to rainfall over the oceans; apply to North Pacific.

Approach: Initially, the JASIN data set will be used to test the theory relating rainfall to radiometric brightness observed by the satellite, particularly its assumptions and its sensitivity to explicit but ancillary atmospheric variables such as raindrop size distribution, and the height of the freezing layer. Later, methods will be developed to use satellite and surface observations to parameterize these ancillary variables so that satellite observations can be converted to rainfall in less well instrumented areas. Ultimately, the goal is to be able to map oceanic rainfall over the North Pacific with better accuracy than the year-to-year variability in rainfall.

Status: No work has been conducted on this project thus far. The principal investigator has been working half-time for JPL and half-time for ONR. Consequently, no time was left to work on this Program. It is planned to assign a co-principal investigator to work full-time on the rainfall problem along with the present principal investigator.

This work is supported jointly by NOAA and NASA.

## RADAR STUDIES OF THE SEA SURFACE

Principal Investigator: Dr. Robert H. Stewart 183-336  
Jet Propulsion Laboratory  
Pasadena, CA 91103  
(213) 354-5079, FTS 792-5079

Long-Term Objective: Radio signals scattered from the sea surface carry information about processes operating at the surface and about undersea phenomena which influence the surface. My long-term objective is to use scattered radio signals to study surface and internal waves, currents, and current shear at the surface. The work uses radio wavelengths ranging from dekameter to centimeter and is providing fundamental new information on wave growth and decay and the forcing of surface currents by wind and wave fields.

Specific Objectives (Synthetic-aperture radar): Maps of the strength of radio scatter from the sea produced by synthetic-aperture radar (SAR) show patterns that appear to be produced by surface and internal waves, patchiness of the wind field, and perhaps ocean currents. Working with John Vesey of Stanford and Robert Shuchman of the Environmental Research Institute of Michigan, I am investigating the ability of SAR to observe surface waves as a function of azimuth angle (relative to the wave propagation direction), wave height and length, and surface wind speed. To do this, we are comparing images of the sea surface made by SEASAT during the JASIN experiment off Scotland with waves measured by a buoy deployed on the surface, together with images of the sea made at various azimuth angles during earlier experiments off California and Florida. In addition, the JASIN images are being used to determine the phenomena responsible for the large (1-100 km) features seen in these images. In particular, we wish to know whether the features are oceanic or atmospheric, whether they may be due to currents or current shear, and their relationship to bottom topography.

(Satellite Oceanography): The techniques for observing the sea from space have been developed by many different disciplines, including planetology, radar astronomy, and meteorology, and described in a widely scattered literature. To synthesize this material and make it readily available to the oceanographic community, I have written a rough draft of a book on "Methods of Satellite Oceanography." I intend to rewrite this for publication in 1981.

This work is jointly supported by NASA and the Office of Naval Research.

ENHANCEMENT OF SEASAT WIND-STRESS MEASUREMENTS USING DATA FROM GOES

Principal Investigator: Dr. Verner E. Suomi  
Space Science and Engineering Center  
University of Wisconsin-Madison  
1225 West Dayton Street  
Madison, Wisconsin 53706

Objective: To resolve the directional ambiguity of the wind and stress measurements from the scatterometer and to improve their quality by using the cloud motion winds from GOES.

Approach: The principle involved is that low level cloud motions are highly correlated with surface winds over the ocean. Thus, cloud motion vectors can be transformed into estimates of surface winds with modification for boundary layer effects. These independent data can be used for selecting the correct scatterometer solution and providing quality control checks on the solution. The approach to the problem will be to assume a value for the frictional wind changes below cloud base using tabulated data and any other pertinent literature. A second component of the wind change will be calculated from the temperature gradients. These two corrections will be used to approximate the surface wind from the cloud motion wind and the closest scatterometer solution can then be selected.

Status: Studies of ship and island based radiosonde data have verified that low level cloud motions can usually discriminate the correct surface wind direction within 25°. The effect of time and space scales of averaging on the agreement of cloud motions and surface winds at low latitudes are being studied with data from NOAA buoys. A system has been devised for semiautomated editing of SEASAT Scatterometer vectors using nearby clouds, and several trial data sets produced. These data are being employed to study the statistical properties of the observed surface directions in relation to cloud motion directions, as well as the relationship of the speeds. Scatterometer speeds are also being compared with values obtained from sunglint.

This work is supported jointly by NOAA and NASA.

## ADVANCED OCEAN SENSOR SYSTEMS DEVELOPMENT

Principal Investigator: C. T. Swift, NASA Langley Research Center, Hampton, VA 23665, (804) 827-3631 (FTS 928-3631)

The long term interests are to develop precision passive microwave devices and algorithms for the remote sensing of the ocean and ice. Aircraft are utilized as platforms to collect field data for developing unambiguous and accurate geophysical retrievals.

Examples of specific investigation objectives include the development of specialized sensors to measure ocean temperature to within an absolute accuracy of 1°C: salinity to well within an accuracy of 1 ppt.; and the thickness of lake ice to within 5 percent of the average base thickness. Plans are currently underway to collect aircraft data to determine the accuracy of radiometric measurements of wind speed over the ocean.

By utilizing a two frequency radiometer system, it has been demonstrated that temperature and salinity can be synoptically measured to within the accuracy cited above. This was first shown in 1976 during overflights of the Chesapeake Bay, and more recently during four flights conducted at the mouth of the Savannah river. The latter flights were conducted at various times of the tidal cycle in order to observe the dynamics of the salinity wedge.

A mission performed last winter over the Great Lakes ice cover has shown that microwave radiometers indeed respond to changes in the base thickness. More extensive remote measurements and supporting surface truth were done this year, and data processing is underway to establish the resultant accuracy of the measurements.

## MICROWAVE REMOTE SENSING OF ICE PROCESSES

Principal Investigator: C. T. Swift, NASA Langley Research Center, Mail Stop 490, Hampton, VA 23665, 804 827-3631, FTS (928-3631)

The long term interests of this research area is to develop combined active and passive microwave remote sensing methods for the classification of polar ice. To this end, recent research activities have indicated that up to seven categories of ice can be identified if an active microwave channel is used in concert with radiometers.

The specific immediate investigation objectives are to analyze active and passive microwave data in hand. Aircraft data were collected, in conjunction with ground truth, during three major joint expeditions to the Arctic. These expeditions included a 1978 experiment in the Beaufort Sea, which focussed on the radar signature of ice ridges; a 1979 revisit to the area which included complementary radiometric measurements; and the 1979 Norwegian Sea Experiment (NORSEX) which concentrated on microwave remote sensing of the ice edge. In addition to the backlog of aircraft data under analysis, the effort will include reduction of satellite data collected during the 99 day lifetime of Seasat.

A total of 21 aircraft remote sensing flights were undertaken in the three field experiments listed above. The approach to the data reduction has been to work closely with the other principal investigators to (1) establish priorities, (2) to agree on the data products to be supplied by each investigator and (3) to meet periodically, in a workshop atmosphere, to bring material together for reporting in a timely fashion. In the case of NORSEX, it means pulling together reduced data to be supplied by Langley, Goddard, and the Norwegian surface truth team. A similar plan is being followed, with separate investigators, to reduce other flight data.

These field experiments represent the first time that precision and versatile microwave instruments have collected data over polar ice, and several significant results have been obtained. To name a few, the precision radiometer has provided the first indication that first year ice and multi-year ice can be discriminated at C-Band; the frequency stepping capability of the radiometer was utilized to discriminate thin ice from thick ice and simultaneous data collected by the scatterometer and radiometer during flights into the ice edge has, indeed, verified the complementary nature of the two sensors.

## GEODETIC STUDIES WITH SEASAT-A

Principal Investigator: Dr. Manik Talwani  
Lamont-Doherty Geological Observatory  
Columbia University  
New York, NY 10028

Objective: To evaluate the sensitivity of Seasat-A altimetry measurements and their ability to resolve oceanographic and geological effects, and to interpret features defined by the altimetry measurements in terms of oceanographic and tectonic phenomena and geographic structure.

Approach: Gravimetric geoids will be constructed in the western North Atlantic and in the western Pacific based on all available gravity data for comparison with Seasat-A data. Comparison between altimeter determined sea surface heights and the gravimetric geoid will be used in estimating the sea surface topography attributed respectively to oceanographic phenomena and to gravity variations.

Status: We have concentrated on a small area in the western North Atlantic between 30°N and 34°N latitude and 74°W and 30°W longitude. This area has been well surveyed by surface oceanographic ships. We have constructed a GEOS-3 altimetry geoid for the area, based on 160 profiles crossing through the area which have been adjusted for bias errors. Six nearly coincident Seasat-A profiles cross the area from southeast to northwest, passing over the continental margin and gulf stream at nearly right angles. Preliminary examination of the profiles shows that significant differences between different profiles and between the Seasat-A and GEOS-3 sea surface heights are clearly defined and may be related to transient oceanographic effects such as the migration of the gulf stream and eddies, and tides.

The most important result of the program to date is the identification of a clearly defined oceanographic signal, as seen from the differences between coincident Seasat profiles. The quality of the data is excellent. Features with widths as low as 20 km and amplitudes of several tens of cm are resolvable, a substantial improvement over the resolution of the GEOS-3 data.

This work is supported jointly by NOAA and NASA.

A STUDY TO REMOTELY DERIVE PRECIPITATION RATES FROM MICROWAVE AND INFRARED RADIOMETRY AND TO EMPLOY SEASAT-A MEASUREMENTS TO DETERMINE PRECIPITATION IN HURRICANES

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Objective: Seasat-A SMMR data will be used to demonstrate the remote determination of rainfall rates by microwave radiometry. The proposed study will build upon experience gained in the analysis of Nimbus-5 ESMR data, and an important objective will be to utilize the SMMR data to monitor rainbands in hurricanes during the course of their evolution.

Approach: Develop rainfall analysis procedures taking advantage of SMMR multispectral microwave imagery supplemented mainly by infrared experience. Obtain ground truth from digitized radars, such as in the D-Radex and those in operational NWS networks which provide VIP displays. Raingage network data will be obtained for ground truth to check the rainfall rates inferred from Seasat-A observations. Rainfall distributions from Seasat-A will be tracked as hurricanes develop. The analysis will be extended to include the effects of capillary waves and foam.

Status: SMMR data is required for those times when the Seasat passed over hurricanes in the Caribbean. For these hurricanes, the National Hurricane Laboratory in Miami has valuable comparative ground truth in the form of aircraft-borne radar measurements. Thus far, none of the requested SMMR data has yet been released to us. We are therefore exploring the feasibility of using Nimbus 7 SMMR data for this study.

This work is supported jointly by NOAA and NASA.

A TWO-SCALE MODEL FOR RADAR SCATTERING  
FROM THE OCEAN SURFACE

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The objective of this investigation is to develop a theoretical model to describe the scattering and emission of electromagnetic waves from the ocean's surface. A normalized radar cross section (NRCS) model was developed in 1977 using two-scale scattering theory in which the scatterometer footprint was segmented into regions having dimensions large compared to the radiation wavelength. These regions will, in general, be tilted with respect to the mean surface across the footprint. A tilt probability is assigned, and the overall NRCS is found by integrating over the regional NRCS weighted by the tilt probability and a geometric factor necessary to insure energy conservation. Furthermore, the NRCS for a particular region depends upon the wave number spectrum of the sea-surface roughness within the region. This dependence is due to Bragg scattering by sea waves having wave numbers similar to the radiation wave numbers.

At present the scattering theory contains 14 physical parameters characterizing the wind-driven sea surface which by definition should be independent of the radar parameters. Work is planned to estimate these parameters using aircraft and satellite microwave scatterometer measurements and to test for dependence with the polarization of the electric field vector. If the dependence is significant, then modifications to the theory will be suggested. Further, the NRCS model will be expanded to compute cross-polarized backscatter and will be compared with aircraft scatterometer measurements.

## OPTICAL PROPERTIES OF TURBID COASTAL WATERS

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Our long-range interest is the development of reliable data analysis procedures for the identification and quantification of various water constituents from passive remote-sensing data. One reason for the unreliability of most present concepts is the lack of detailed scientific understanding of the two-fold marine optical physics process in which changes in water chemistry and physics create changes in underwater optical properties which in turn cause changes in the upwelled radiance being measured by the remote-sensing instrument.

The major objective of this investigation is a fundamental understanding of the turbid-water optical physics process. Definition of the effects of various major water constituents on the remote-sensing signal and the development of a technique for monitoring remote-sensing penetration depth are also objectives.

The approach for this investigation is to make both laboratory and field measurements of four underwater optical parameters, three remote-sensing parameters, and a number of physical-chemical properties for each sample of water at visible and near-infrared wavelengths. Tests will be conducted on a number of water samples representing a wide variation in water chemistry and turbidity. Underwater optical parameters will be input to several existing analytical models to test their validity and limitations for calculating reflectance. Statistical correlation studies will be made in an attempt to relate underwater optical coefficients to such physical-chemistry parameters as particle size distribution, inorganic suspended solids, particulate organic carbon, dissolved organic carbon, chlorophyll a, cell count etc.

The initial phase of the investigation has been development of a system of instruments for measurement of the spectral variation of beam attenuation coefficient, absorption coefficient, and volume scattering function for turbid waters to complement existing instruments. This phase is essentially complete. Measurements have now begun on waters with beam attenuation coefficients between  $5 \text{ m}^{-1}$  and  $75 \text{ m}^{-1}$  with different combinations of inorganic suspended sediment, particulate organic carbon, dissolved organic carbon, and chlorophyll a. To date, 23 tests have been conducted and these data are presently under analysis.

## SMMR ALGORITHM REFINEMENT TASK

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The purpose of this task is to refine the algorithm used for retrieving the temperature and wind speed at the ocean surface, to improve their accuracy, to understand their limitations and, where possible, to reduce those limitations.

In analyzing the Seasat SMMR data, large biases in the retrieved parameters were found which resulted from biases in the brightness temperatures. To an extent these biases could be simply subtracted from the data and analysis could proceed. However, internal to the GSFC algorithm, a decision is made as to whether the wind is greater or less than 7 m/s. The biases are such that the decision is always that the wind is greater than 7 m/s resulting in minor degradation of the sea surface temperature retrieval and a total inability of the wind speed algorithm to handle winds less than 7 m/s. A reformulation of the sea surface temperature algorithm to eliminate this problem has been completed and a reformulation of the wind speed algorithm to mitigate but not eliminate this problem is in progress.

Two months of data from Nimbus-7 SMMR have been reduced to brightness temperature and corrected for scan dependent bias problems. The first six days have been reduced to the various ocean parameters and global maps have been prepared. The sea surface temperatures and water vapor maps look surprisingly good but identifiable and correctable problems were found. A data set is being produced which merges the brightness temperatures with ocean stations and data buoy observations.

THE USE OF SATELLITE REMOTE SENSING FOR THE IDENTIFICATION  
OF OCEAN FRONTS AND ITS APPLICATION TO ATLANTIC BLUEFIN  
TUNA UTILIZATION AND MANAGEMENT

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Long-Term Interests: To contribute to fisheries forecasting, and resource utilization and management through use of satellite remote sensing of the ocean as a primary input source.

Specific Investigation Objectives: Using available satellite systems, e.g. NIMBUS-Coastal Zone Color Scanner; TIROS, GOES, NOAA-infrared and visible; LANDSAT-Multispectral Color Scanner, to integrate multispectral with infrared and visible remotely sensed data for the identification and study of such environmental dynamics as circulation, frontal history and ocean productivity. These ocean conditions are being correlated with distribution, movements, availability, catch, and spawning success of Atlantic bluefin tuna in North Carolina-Virginia coastal waters and in the Gulf of Mexico. Similar fisheries data are also being analyzed for other species including skipjack tuna (Katsuwonus pelamis), bluefish (Pomatomus saltatrix) and the sand lance (Ammodytes americanus).

Approach: Derived apparent relationships between environmental and fisheries variables will be cross-correlated with forcing mechanisms, such as surface transport, upwelling, mixing, winds, insolation, etc. Appropriate satellite imagery tapes, including CZCS, are being processed using the RSMAS-University of Miami's interactive computerized display system (black and white and color enhancement). Mr. Mitchell Roffer, a graduate student at the RSMAS, is involved in the project for his Ph.D. dissertation. In addition to University of Miami personnel, this project is being carried out in close cooperation with scientists from (a) the NOAA-National Marine Fisheries Service, Southeast Fisheries Center, Miami (Dr. Fox, Director; Dr. W.J. Richards, Miami; Dr. A. Kemmerer, Pascagoula and NSTL.), (b) the NOAA-Atlantic Oceanographic and Meteorological Laboratories (Dr. G. Maul) and (c) NOAA-National Environmental Satellite Service (Dr. S. Baig).

Status: First year of 3 year project commenced 1 April 1979; fisheries, environmental and satellite data for the 1979 bluefin season in the Gulf of Mexico (Feb.-April) and in North Carolina-Virginia waters (May-July) are currently being analyzed.

DETERMINATION OF THE GENERAL CIRCULATION OF THE OCEAN AND THE  
MARINE GEOID USING SATELLITE ALTIMETRY

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Objective: This program has the ambitious objective of determining the general circulation of the ocean, including its variability, and improving the global marine geoid through use of satellite altimetry and related measurements. As such it involves combining in novel fashion observation and theory from hitherto disparate branches of oceanography along with satellite geodesy. The short term goal is to use the existing altimetric data sets from Geos-3 and Seasat to determine the large scale ocean circulation. In the longer term, we expect to fully understand the potential use of hypothetical future altimetric missions.

Status: The project began under joint NOAA/NASA sponsorship about 15 months ago. The first year of the joint work was principally devoted to acquiring a zero order understanding of the little Seasat data which were available. In particular, we sought to quantify the error sources involved in using altimetry in computing surface geostrophic currents for studying the time average general circulation. It was shown in a paper to be published (Wunsch and Gaposchkin, 1980) that one must deal with three global fields: the altimetric height (including orbit and instrument error), the marine geoid, and the ocean water density as a function of depth. Each field has an associated set of errors of varying magnitude and wave number dependence. Inverse theory provides the natural mathematical tool for combining extant measurements into a unified system. More recent work has been directed at specific issues. V. Zlotnicki, as part of his doctoral thesis, is devising methods based on inverse theory for optimal construction of marine geoids from surface gravity and orbital measurements. With NSF support, we have constructed an interim sea surface, relative to the geoid, from the historical hydrographic data base in the North Atlantic (Wunsch, 1980). Unlike previous surfaces, this one does not rely upon a level-of-no-motion. We are also studying the tidal correction to the altimetry as well as the waveheight bias algorithms. In the near future, we anticipate producing for the western North Atlantic both an oceanographic circulation scheme and an optimum geoid corrected for ocean currents. As more Seasat data becomes available, along with the hitherto unavailable corrections (e.g. water vapor) we anticipate beginning a study of the circulation temporal variability.

TIMING AND DYNAMICS OF THE SPRING AND AUTUMN  
BLOOM IN THE GULF OF MAINE AND GEORGES BANK:  
ECONOMIC RAMIFICATION TO PELAGIC FISHERIES

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The physical oceanographic factors which regulate primary production have been known in a general sense for a number of years. However, the biological oceanographer still cannot adequately predict with any degree of confidence - seasonal changes over wide areas of the oceans. One of the keys to doing this involves knowing the degree to which the water column is mixed vertically and being able to identify areas where vertical mixing is induced by tidal currents or is regulated by heat input and surface winds.

Changes in the degree to which the water column is mixed has been examined over large areas using a combination of infra-red and color imagery - coupled with sea truth observations. Throughout the Gulf of Maine some of the most prominent mixing features are in areas where tidal-current and bottom friction mix the water column. The surface waters of these areas are characterized by low water temperatures and high concentration of phytoplankton chlorophyll. The areas persist as fronts, the most prominent are, Georges Bank, Nantucket Shoals and at the mouth of the Bay of Fundy. These fronts appear to be areas of high steady state productivity which are independent of seasonal temperature and light conditions. They are in contrast to the basin areas of the Gulf of Maine. The surface waters of Wilkinson and Jordon Basins undergo marked seasonal pulses as the result of seasonal differences in heat input and surface winds.

Most of the tidal friction models cannot account for changes in the buoyancy of the water column due to freshwater input. In conjunction with Dr. James Mueller (GSC) we are attempting to examine the contribution of freshwater inflow on buoyancy of the water column and demonstrate how that is reflected in the spatial distribution of phytoplankton chlorophyll. The sea truth program to aid Mueller with this modeling and imagery analysis has been carried out with members of the Scripps Institution Visibility Laboratory (R. Austin and R. Smith). Additional support: NASA, NSF, NOAA, FDA and the State of Maine.

## INVESTIGATION: ICE SHEET ELEVATION FROM SATELLITE ALTIMETRY

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### DESCRIPTION:

The objectives are to:

- a. develop methods to obtain more accurate ice sheet elevation and surface undulations from Seasat-1 and GEOS-3 radar altimetry,
- b. evaluate precision and accuracy of the measurements,
- c. develop methods for deconvolving effects of surface slope.

The investigation includes the following sub-elements: 1) elevation mapping; 2) waveform analysis, tracking, and correction factors; 3) reference level studies and accuracies; 4) sloping surface effects and deconvolution; and 5) analysis of surface undulations, waves, and sastrugi. Emphasis is placed on improving the accuracy of the measurements and on processing both GEOS-3 and Seasat data to produce accurate elevation maps using the new algorithms developed.

Previous research has shown that the surface elevation of the continental ice sheets can be mapped by satellite radar altimetry to a precision of several meters. Analysis of Seasat radar altimetry shows that extensive data on surface elevation has been acquired during several months of Seasat operation. However, about 30 percent of the data was lost due to limitations of the altimeter tracking. Waveform analysis has shown that the loss of tracking is due to surface undulations or large surface slopes that causes height-change rates beyond the capability of the tracking circuit. In addition to the occasional loss of height data, the height data on the sensor data records is frequently in error by typically 5 meters, which is also due to the limited tracking response. A retracking algorithm has been developed to calculate the correct height from the waveform data. Selected height profiles using the new algorithm have been plotted. Future plans include processing of all available GEOS-3 and Seasat altimeter data and generation of topography maps.

INVESTIGATION: MESOSCALE ICE DYNAMICS

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DESCRIPTION:

The objective is to develop and improve methods for extraction of sea ice parameters from multispectral passive microwave and other space data, for use in studies of ice/ocean/atmosphere processes, ice dynamics research, and commercial/operational applications. Specific emphasis is placed on improving the accuracy of sea ice concentration and sea ice type parameters, and on techniques for studying the rate-of-change of these parameters.

The approach is based on current understanding of the physics of microwave emission from sea ice. The microwave emissivity at a given microwave wavelength, polarization, and viewing angle depends on the dielectric characteristics and physical structure of the ice. These properties in turn vary with ice type (e.g. first-year, multi-year, snow-covered first-year, first-year thin). Several emissivities, such as the emissivity of first-year ice at the ESMR wavelength of 1.55 cm, are well-known. Others have been estimated or empirically determined. The data used in the investigation include: ESMR from Nimbus 5 (1.55 cm, 1972-1978), ESMR from Nimbus 6 (0.8 cm, 2 polarizations, 1975-76), SMMR (5 frequency, 2 polarizations, November 78 to present), aircraft data, infrared surface temperature, visible imagery, and surface measurements of ice properties and microwave emission. The sea ice parameters extracted from the microwave data are developed in various formats suitable for ice research. Interactive access to time series of satellite data is used to analyze the time variations of the microwave data and their relations to ice phenomena.

The accuracy of the Antarctic sea ice concentration maps derived from the single-frequency ESMR has been improved to approximately 10% in most regions by using ice temperatures estimated from climatological air temperatures. Daily ice concentration maps were prepared and differenced to produce maps of rate-of-change in ice concentration, which can be related to the rate of new ice production.

Future studies will emphasize the use of multi-frequency passive microwave in combination with active microwave data. Improved determinations of ice parameters will require a better understanding of the quantitative dependences of the radiative emission and backscattering on microscopic and macroscopic ice properties. Therefore, additional studies will be undertaken on the physical structure and dielectric properties of ice as they affect the observed radiative emissions and backscattering.



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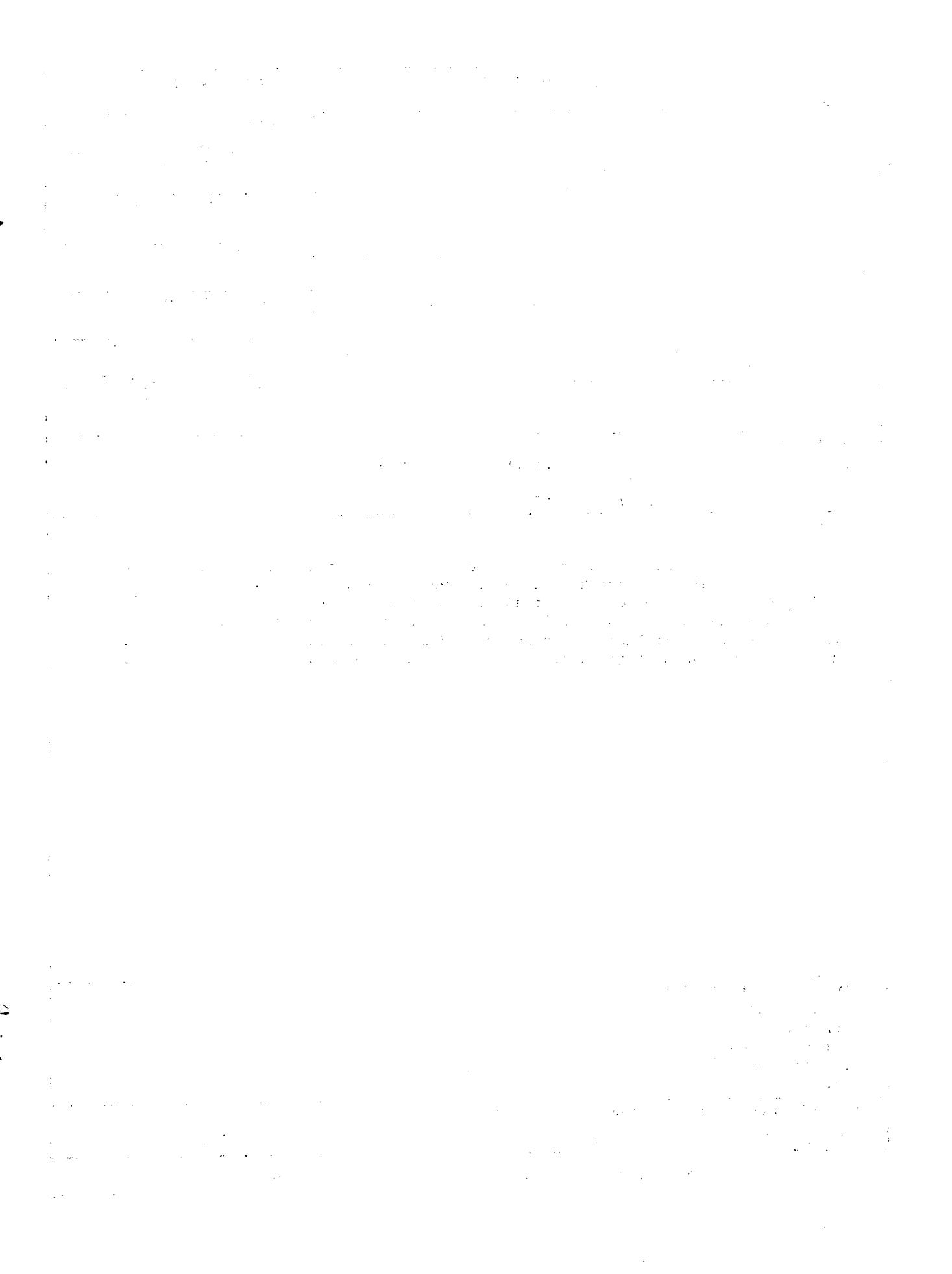
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